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Mining Applications of Life Support Technology

Proceedings: Bureau of Mines Technology Transfer Seminar, Pittsburgh, PA, November 20, 1986

Compiled by Staff, Mining Research

UNITED STATES DEPARTMENT OF THE INTERIOR

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UNITED STATES DEPARTMENT OF THE INTERIOR
Donald Paul Hodel, Secretary

BUREAU OF MINES
Robert C. Horton, Director

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PREFACE

The papers contained in this Information Circular reflect the results of a Bureau of Mines research effort to improve life support technology used by the mining industry. The papers provide practical, up-to-date information concerning the use of mine rescue breathing apparatus and improved equipment for mine rescue teams. Such information can positively impact the mining community by enhancing mine workers' chances of surviving an underground mine disaster.

The seven papers were presented at a technology transfer seminar on mining applications of life support technology in November 1986. Technology transfer seminars represent a major portion of the Bureau's technology transfer program, which is designed to bring useful research results to industry's attention so that they can be adopted without delay. Those desiring further information about developments resulting from other Bureau research programs should contact the Bureau of Mines, Branch of Technology Transfer, 2401 E St., NW, Washington, DC 20241.

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

°C	degree Celsius	lb	pound
cm	centimeter	m	meter
cu in	cubic inch	mi/h	mile per hour
h	hour	min	minute
in	inch	mm	millimeter
kg	kilogram	ms	millisecond
L	liter	s	second
L/min	liter per minute	yr	year

MINING APPLICATIONS OF LIFE SUPPORT TECHNOLOGY

Proceedings: Bureau of Mines Technology Transfer Seminar, Pittsburgh, PA, November 20, 1986

Compiled by Staff, Mining Research

ABSTRACT

The Bureau of Mines has conducted considerable research to improve life support technology for underground mining applications. This proceedings volume presents several new developments that may help increase the chances of mine workers in surviving underground disasters. Several papers address the performance of present self-contained self-rescuers (SCSR's) and provide proposed guidelines for the design and testing of a second-generation SCSR. Improvements in the safety and effectiveness of mine rescue and recovery operations are described, including the design of a low-profile rescue breathing apparatus and a rescue team helmet.

INTRODUCTION

The Bureau of Mines life support research program is directed toward research into and development of breathing apparatus technology that increases the chances of miners surviving or being rescued after an underground mine disaster. When a mine disaster occurs, the basic survival technique for a miner is to escape from the mine. Following a mine fire or explosion, the atmosphere inside the mine sometimes becomes oxygen deficient or filled with toxic gases. Under these circumstances, escape is nearly impossible unless a miner is equipped with a self-rescue device that supplies oxygen without the need for breathing mine air. Federal regulations (30 CFR 75.1714) require that every person who goes into an underground coal mine in the United States must be supplied with a self-contained self-rescuer (SCSR), a device capable of providing at least 1 h of oxygen regardless of ambient atmosphere. Only SCSR's approved by the National Institute for Occupational Safety and Health (NIOSH) and the Mine Safety and Health Administration (MSHA) can meet the provisions of the regulations. All of the 1-h-duration SCSR's are much larger and heavier than the conventional filter self-rescuer (FSR) which a miner wears on his or her belt as personal protective equipment. Unlike oxygen self-rescuers, FSR's protect only against low levels of carbon monoxide. Because of the size and weight of the 1-h SCSR's, in most cases the mining industry has elected to comply with the SCSR regulations by deploying the apparatus in a carry and store mode, which involves transporting the SCSR's into and out of the mine on a shift basis. The carry and store mode allows the miner to store the SCSR within 5 min of the work site, provided that he or she continues to wear an FSR. The Bureau is conducting research to develop a second-generation, person-wearable SCSR (PWSCSR) that is approximately twice the size and weight of an FSR. A PWSCSR meeting these requirements could be worn on a miner's body, making it immediately available in the event of an emergency.

A mine disaster may also result in the entrapment of miners whose normal egress from the mine is cut off. This often necessitates a rescue operation by a specially trained and equipped mine rescue team sent into the mine from the surface. Other Federal regulations (30 CFR 49) specify that mine rescue teams must be provided with rescue breathing apparatus (RBA's) that have at least 2-h service time and are approved for in-mine use. The Bureau of Mines is pursuing the development of smaller, lighter weight RBA's appropriately designed for use in the postdisaster environment, especially for low-coal rescue and recovery missions. Another related technology involves the development of a rescue team helmet designed to integrate full head and eye protection with communication, illumination, and life support functions.

The papers presented in these proceedings address some of the recent research conducted by the Bureau of Mines that has been directed toward the life support problems outlined above. The topics covered range from basic research on the respiratory physiology of mine escape to new SCSR training programs. Any questions or comments pertaining to this research are encouraged and appreciated.

Throughout the proceedings, mention of trade names is made to facilitate understanding; this mention does not imply endorsement by the Bureau of Mines.

OVERVIEW OF LIFE SUPPORT ESCAPE BREATHING APPARATUS TECHNOLOGY

By John G. Kovac[1] and Nicholas Kyriazi[2]

ABSTRACT

This paper provides an overview of life support technology available today that is designed to meet the requirements of emergency escape following a mine disaster. The basic kinds of escape breathing apparatus are described, and U.S. and foreign experience with this technology is examined.

INTRODUCTION

When a mine disaster occurs, the basic survival technique for a miner is to escape from the mine. Following a mine fire or explosion, the atmosphere inside a mine may become oxygen deficient or filled with toxic gases. Under these circumstances, escape is impossible unless a miner is equipped with a self-contained breathing apparatus.

The purpose of this paper is to review the respirator technology available today to meet the requirements of emergency escape following a mine disaster.

This paper is organized into three sections. The first section defines the self-contained self-rescuer (SCSR). The next section describes the basic kinds of SCSR technology. Both U.S. and foreign experience with SCSR technology are examined in the third section.

DEFINITION OF SCSR

Federal regulations (30 CFR 75.1714) require that every person who goes into an underground coal mine in the United States be supplied with an SCSR. An SCSR is an emergency breathing apparatus designed for the purpose of mine escape. It must be capable of providing at least a 60-min supply of oxygen (O_2). Only SCSR's approved by the Mine Safety and Health Administration (MSHA) and the National Institute for Occupational Safety and Health (NIOSH) meet the provisions of these regulations.

Other nations, including the Federal Republic of Germany and the U.S.S.R., have developed self-contained breathing apparatus designed for mine escape. Although some of these apparatus are not approved for use in the United States because they do not satisfy performance or duration requirements contained in Federal regulations for testing and certification of respirators (30 CFR 11), all of these devices will be referred to as SCSR's.

DESCRIPTION OF BASIC TECHNOLOGY

All of the apparatus described in this report are one of two types: chemical-oxygen or compressed-oxygen. Most of the chemical-oxygen apparatus use potassium superoxide (KO_2), a solid chemical, for both the oxygen source and the carbon dioxide (CO_2) absorbent. One of the chemical-oxygen apparatus uses a sodium chlorate ($NaClO_3$) candle for an oxygen source and a separate chemical bed for CO_2 absorption. An engineering drawing of a generic chemical-oxygen SCSR is shown in figure 1.

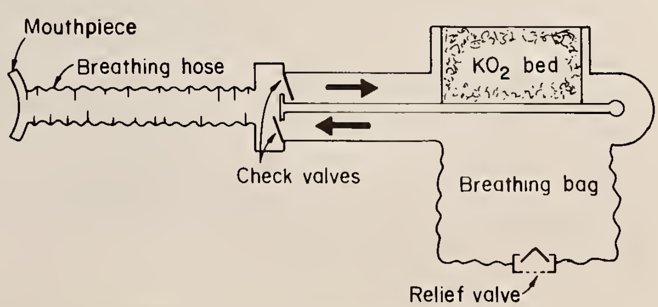

FIGURE 1.—Chemical oxygen SCSR schematic.

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[1]Supervisory mechanical engineer.
[2]Biomedical engineer.
Pittsburgh Research Center, Bureau of Mines, Pittsburgh, PA.

The compressed-oxygen apparatus use bottled oxygen under high pressure for the oxygen source with a separate chemical bed, either lithium hydroxide (LiOH) or soda lime, both solid chemicals, for CO_2 absorption. An engineering drawing of a generic compressed-oxygen SCSR is shown in figure 2.

U.S. AND FOREIGN EXPERIENCE

Worldwide experience in SCSR technology can be broken down into three categories: SCSR's approved by MSHA and NIOSH, Bureau of Mines-developed prototypes, and foreign apparatus. All of the apparatus are listed in table 1, with their rated service lives, country of origin, oxygen source, and size and weight. The sizes and weights of the different apparatus are also shown in bar chart form in figures 3 and 4. The PASS and the MSA 10/60 are not shown, the PASS because, it is unusual and unrepresentative and the 10/60 because it has two parts.

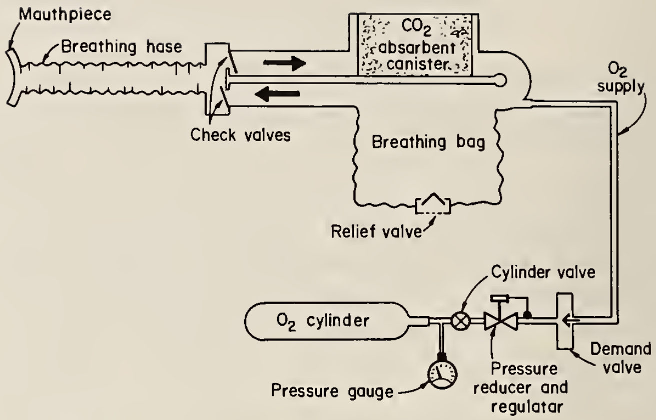


FIGURE 2.—Compressed oxygen SCSR schematic.

MSHA-NIOSH-Approved SCSR's

CSE AU-9A1

The AU-9A1 (figs. 5-6) is a compressed-oxygen self-rescuer with a throwaway steel bottle but otherwise reusable parts. It is field serviceable by trained personnel only. It has a

TABLE 1. - Oxygen self-rescuers tested

Apparatus	Rated duration, min	Country	O_2 source	Weight, lb In use	Weight, lb In case	Volume, in^3
NIOSH-APPROVED						
CSE AU-9A1........	60	United States	Cylinder.....	9.48	10.91	384
Draeger OXY-SR 60B	60	Germany (FRG)	KO_2..........	7.49	8.38	459
MSA 60-min SCSR...	60	United States	KO_2..........	6.61	8.91	506
Ocenco EBA 6.5....	60	...do........	Cylinder.....	6.83	7.74	528
PASS 700..........	60	...do........	...do........	14.55	18.96	2,439
U.S.D. SCEBA-60...	60	...do........	...do........	7.14	7.56	453
BUREAU PROTOTYPES						
Lockheed PBA[1].....	60	United States	KO_2..........	4.41	4.65	210
MSA 10-min PBA[1]...	10	...do........	KO_2..........	1.81	2.73	144
MSA 10/60[1]........	70	...do........	KO_2..........	10.43	NA	NA
Westinghouse PBA..	60	...do........	$NaClO_3$ candle	3.85	7.58	459
FOREIGN--NOT NIOSH-APPROVED						
Auer SSR-90.......	90	Germany (FRG)	KO_2..........	6.79	10.34	310
AZG-40............	40	China........	KO_2..........	3.70	4.48	253
Draeger OXY-SR 30.	30	Germany (FRG)	Cylinder.....	5.27	5.27	369
Draeger OXY-SR 45.	45	...do........	...do........	5.27	5.27	369
Fenzy Spiral II...	45	France.......	KO_2..........	6.72	7.69	400
WC-7..............	45	U.S.S.R......	KO_2..........	5.62	6.48	196

NA Not available.
[1]NIOSH-approved prototype.

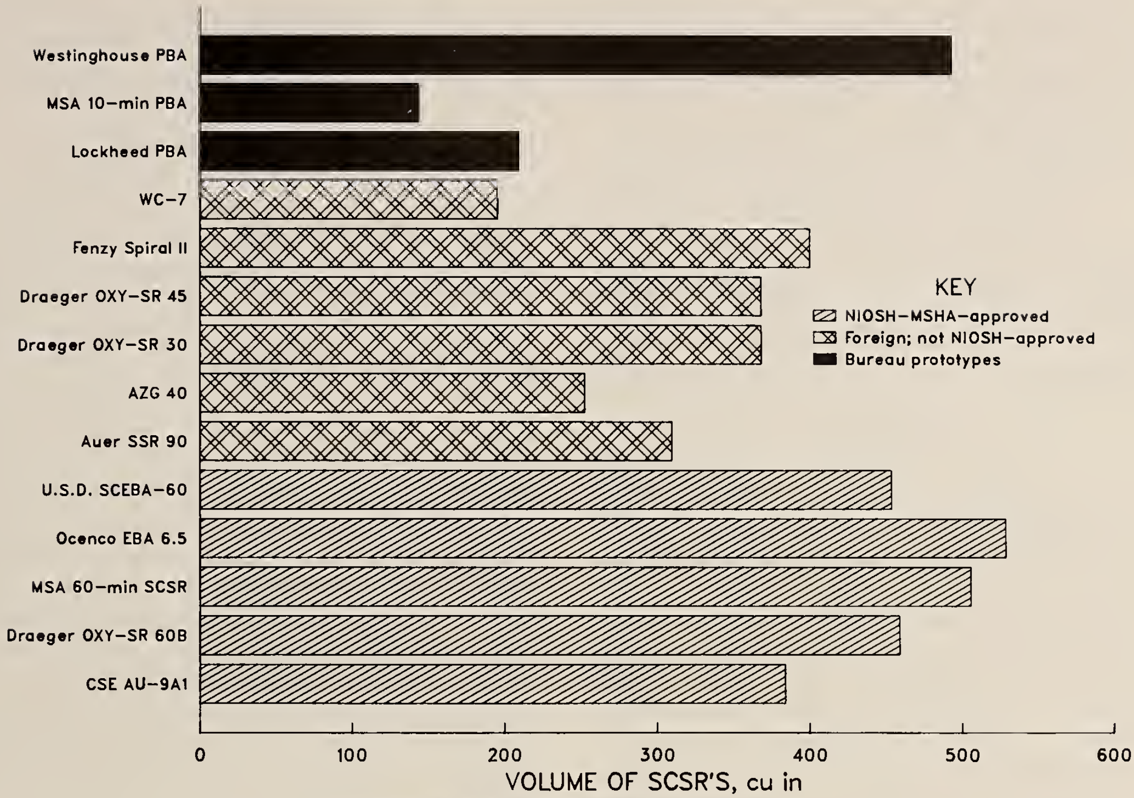


FIGURE 3.—Size comparison bar chart.

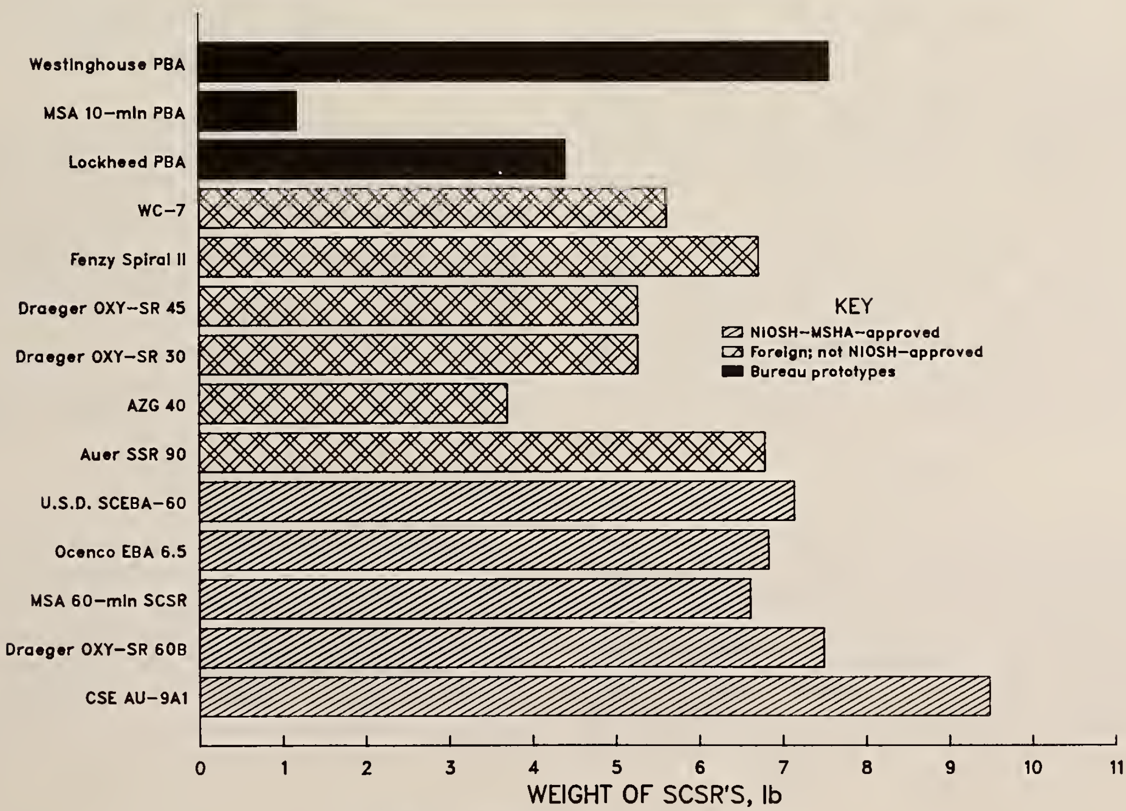


FIGURE 4.—Weight comparison bar chart.

bidirectional flow path, a constant O_2 flow of at least 1.5 L/min, and a pressure-activated demand valve and relief valve. The cylinder contains 130 L O_2, and the CO_2 absorbent is LiOH.

Draeger OXY-SR 60B

The OXY-SR 60B (figs. 7-8) is a chemical-oxygen self-rescuer which can be returned to the distributor, National Mine Service, for refurbishing. It has a unidirectional flow path through the KO_2 bed and a pressure-activated relief valve. A chlorate candle is provided for an initial spurt of oxygen until the KO_2 bed is sufficiently activated by the user's breath. The KO_2 is pelletized.

MSA 60-Min SCSR

The MSA SCSR (figs. 9-10) is a chemical-oxygen self-rescuer that is entirely throwaway. It has a unidirectional flow path through the KO_2 bed and a volume-activated relief valve. A chlorate candle is utilized for initial oxygen flow. The KO_2 is in granular form.

Ocenco EBA 6.5

The EBA 6.5 (figs. 11-12) is a compressed-oxygen self-rescuer with a fiberglass-wrapped, reusable aluminum bottle. The apparatus is refurbishable only by the manufacturer. It has a unidirectional flow path with directional check valves in the mouth bit assembly, a constant flow of at least 1.5 L/min, and pressure-activated demand and relief valves. The cylinder contains 157 L O_2, and the CO_2 absorbent is LiOH.

PASS 700

The PASS (Portable Air Supply Systems) self-rescuer (figs. 13-14) is a compressed-oxygen system with an aluminum bottle which is reusable after refurbishing by the manufacturer. It has a unidirectional flow path through the CO_2 scrubber, an enclosed breathing bag, no demand valve, a constant flow of oxygen of at least 3 L/min, and a pressure-activated relief valve. The cylinder contains 240 L O_2, and the CO_2 absorbent is soda lime. This apparatus is no longer being produced.

U.S.D. SCEBA-60

The SCEBA-60 (figs. 15-16) is a compressed-oxygen system that has some reusable parts; it is not presently being commercially produced because it became available only after mine operators were required to have placed orders for their oxygen self-rescuers. It has a bidirectional flow path, a constant flow rate of oxygen of at least 1.5 L/min, and volume-activated demand and relief valves. The relief valve is triggered by bag volume but dumps from the breathing hose air that has not yet been scrubbed of CO_2 or enriched with oxygen. The device is available with a standard steel, throwaway bottle or a lightweight, fiberglass-wrapped aluminum, reusable bottle containing 130 L O_2. The CO_2 absorbent is LiOH.

Bureau of Mines-Developed Prototypes

Lockheed PBA (Personal Breathing Apparatus)

The Lockheed PBA (figs. 17-18) is a NIOSH-approved prototype. The apparatus were manufactured in 1974 and stored in warehouses until tested for this study. These chemical-oxygen self-rescuers were intended to be throwaway devices. The flow path is unidirectional with check valves in the mouth bit. It has a pressure-activated relief valve and a chlorate candle for initial oxygen flow.

MSA 10-Min PBA

These NIOSH-approved prototypes (figs. 19-20) were also manufactured in 1974 and were similarly stored in warehouses until being tested. The 10-min PBA is a one-use, chemical-oxygen self-rescuer with bidirectional flow, a chlorate candle, and two breathing bags, one of which contains a volume-activated relief valve.

MSA 10/60 Oxygen Self-Rescuer

These NIOSH-approved prototypes (figs. 21-22) were built in 1979 and were stored until being tested. The chemical-oxygen 10/60 was designed so that the 10-min apparatus could be belt-worn with the 60-min canister being stored. In an emergency, the 10-min device is donned and the user proceeds to the storage place of the 60-min canisters, which are then attached without the need to remove the mouth bit. The oxygen source in both portions is KO_2. Chlorate candles are provided on both portions of the device; the candle on the 60-min portion is automatically activated when the device is attached to the 10-min portion. The entire apparatus is one-use only. The 10-min apparatus has a bidirectional flow path, but when the 60-min canister is attached, the flow path is changed to unidirectional flow. Figure 21 shows the 10-min apparatus in the case and deployed, and the 60-min canister. The 60-min canister does not have its own case but is stored in a plastic bag. Figure 22 is a schematic of the combined apparatus, showing the flow scheme.

Westinghouse PBA

The Westinghouse PBA (figs. 23-24) is the first Bureau prototype ever developed. The apparatus tested were manufactured in 1971 and were not certified by NIOSH. The flow path is bidirectional with a two-chambered breathing bag, one chamber for exhalation and one for inhalation, with a pressure-activated relief valve on the inhalation side of the bag. The oxygen source is a large, L-shaped, $NaClO_3$ candle which provides at least 3 L/min of O_2 flow continuously, regardless of usage rate. The CO_2 scrubber uses LiOH. The original directive for this contract included face protection, and the design included a combination hood-lens-noseclip-mouth-bit. Only three of these prototypes remained for testing in this study.

Foreign Apparatus

Auer SSR-90

The SSR-90 (figs. 25-26), manufactured in the Federal Republic of Germany (FRG) by Auer, a subsidiary of MSA, is a chemical-oxygen self-rescuer which can be user-reburbished. It has a unidirectional flow path through the KO_2 bed, a volume-activated relief valve, and a "quick starter" for initial oxygen flow.

AZG-40

The Chinese AZG-40 self-rescuer (figs. 27-28) uses KO_2 and is not reusable. It has a bidirectional flow path, a volume-activated relief valve which vents from the breathing hose, a heat exchanger, and a quick-starting mechanism for initial oxygen flow.

Draeger OXY-SR 30

The West German OXY-SR 30 (figs. 29-30) is a compressed-oxygen self-rescuer which is user reburbishable. It has a unidirectional flow path through the soda lime scrubber, a pressure-activated relief valve, a volume-activated demand valve, and a constant flow of oxygen of at least 1.5 L/min. The steel cylinder contains 64.5 L O_2.

Draeger OXY-SR 45

The OXY-SR 45 (fig. 31) is nearly identical to the OXY-SR 30 with two differences: The constant flow rate is only 1.2 L/min, and the oxygen flow cannot be turned off once it is activated.

Fenzy Spiral II

The French Spiral II (figs. 32-33) is a chemical-oxygen self-rescuer which is user serviceable. It has a unidirectional flow path through the KO_2 bed and a pressure-activated relief valve. A very small compressed-oxygen bottle is

utilized for initial startup. The bottle is yanked upward by pulling on a plastic ball connected to the bottle; this breaks a metal seal, rapidly releasing the contents into the system.

WC-7

The Soviet WC-7 self-rescuer (figs. 34-35) uses KO_2 as the oxygen source and is throwaway. It has a bidirectional flow path device with a volume-activated relief valve. The starting device utilized delivers 6 L O_2 within 30 s.

PERFORMANCE COMPARISON

A performance study of oxygen self-rescuers from the United States and other countries was undertaken as an assessment of present worldwide technology. The apparatus were tested on a breathing and metabolic simulator in the life support laboratories of the Bureau of Mines. Parameters monitored during the testing were inhaled levels of CO_2 and O_2, inhaled gas temperature, and breathing resistance. The metabolic demand placed on the apparatus represented the average demand of the 50th-percentile miner performing a 60-min Man-Test 4, as described in 30 CFR 11H.

Results presented in tables 2 and 3 include apparatus duration, reasons for terminating a test, and averages and peaks of monitored parameters. Figures 36 and 37 are the comparison curves of weight versus capacity and volume versus capacity, respectively, for SCSR's that are, or could have been, deployed in

TABLE 2. - Means of average values of monitored parameters

(Standard deviations in parentheses)

Apparatus	Duration, min	Cause of termination	O_2, pct	CO_2, pct	Resistance, mm H_2O: Exhalation	Resistance, mm H_2O: Inhalation	Temperature, °C
CSE AU-9A1	73 (6)	High CO_2	70 (13)	2.5 (0.1)	50 (8)	50 (4)	42 (1)
Draeger OXY-SR 60B.	72 (4)	Low bag volume	78 (3)	1.0 (.1)	46 (6)	26 (6)	37 (2)
MSA 60-min SCSR	83 (6)	Low bag volume or high CO_2.	82 (1)	1.0 (.2)	58 (6)	26 (3)	44 (2)
Ocenco EBA 6.5	110 (8)	Low bag volume	74 (7)	.7 (.2)	51 (5)	38 (3)	41 (1)
PASS 700	86 (7)	...do	81 (3)	1.1 (.1)	51 (4)	24 (3)	39 (1)
U.S.D. SCEBA-60	79 (10)	Low bag volume or high CO_2.	71 (10)	2.2 (.4)	54 (7)	56 (2)	40 (1)
Lockheed PBA	34 (9)	High CO_2, low bag volume, or low O_2.	60 (16)	1.6 (.5)	113 (30)	120 (46)	49 (10)
MSA 10-min PBA	14 (1)	High CO_2	44 (4)	1.8 (.2)	63 (8)	119 (5)	47 (3)
MSA 10/60:							
10-min	9 (1)	High CO_2	37 (10)	1.6 (.1)	74 (10)	79 (12)	38 (2)
60-min	73 (21)	Low bag volume	67 (11)	2.2 (.6)	83 (13)	60 (15)	42 (2)
Westinghpouse PBA	60 (1)	...do	84 (1)	.6 (.1)	121 (35)	31 (6)	40 (2)
Auer SSR-90	82 (2)	Low bag volume	81 (5)	.7 (.1)	57 (5)	35 (3)	40 (2)
AZG-40	38 (3)	High CO_2	66 (5)	2.5 (.1)	116 (9)	101 (9)	50 (4)
Draeger OXY-SR 30	47 (4)	Low bag volume	80 (3)	1.5 (.2)	45 (3)	19 (2)	41 (0)
Draeger OXY-SR 45	55 (7)	Low bag volume or high CO_2.	76 (7)	1.6 (.1)	42 (9)	18 (1)	41 (1)
Fenzy Spiral II	34 (3)	Low bag volume	64 (4)	1.7 (.7)	56 (12)	22 (7)	36 (2)
WC-7	67 (4)	High CO_2 or low bag volume.	77 (4)	1.8 (.1)	63 (5)	59 (5)	56 (4)

TABLE 3. - Means of peak values of monitored parameters

(Standard deviations in parentheses)

Apparatus	O_2, pct	CO_2, pct	Resistance, mm H_2O		Temperature, °C
			Exhalation	Inhalation	
CSE AU-9A1	76 (10)	4.0 (0)	56 (9)	55 (6)	44 (2)
Draeger OXY-SR 60B	93 (2)	1.3 (0.1)	83 (18)	45 (19)	44 (3)
MSA 60-min SCSR	91 (2)	3.1 (1.2)	69 (13)	40 (14)	53 (1)
Ocenco EBA 6.5	81 (12)	1.8 (.5)	54 (5)	41 (1)	43 (1)
PASS 700	89 (4)	1.5 (.4)	53 (3)	27 (3)	42 (1)
U.S.D. SCEBA-60	79 (6)	2.9 (.8)	59 (7)	65 (7)	42 (1)
Lockheed PBA	75 (13)	3.4 (1.0)	148 (34)	157 (48)	64 (16)
MSA 10-min PBA	57 (5)	4.0 (0)	82 (15)	221 (13)	53 (3)
MSA 10/60:					
10-min	44 (10)	4.0 (0)	114 (15)	137 (31)	45 (2)
60-min	76 (12)	3.0 (.8)	117 (40)	80 (47)	47 (3)
Westinghouse PBA	91 (1)	.9 (.2)	136 (35)	61 (13)	44 (2)
Auer SSR-90	88 (4)	1.7 (.3)	66 (7)	48 (4)	48 (2)
AZG-40	79 (2)	4.0 (0)	160 (10)	153 (9)	60 (6)
Draeger OXY-SR 30	82 (3)	2.0 (.4)	52 (4)	21 (2)	44 (1)
Draeger OXY-SR 45	81 (8)	2.8 (.9)	48 (7)	21 (3)	44 (1)
Fenzy Spiral II	89 (1)	2.0 (.7)	80 (29)	42 (19)	43 (2)
WC-7	85 (5)	3.8 (.4)	75 (9)	78 (12)	69 (5)

large numbers in underground mines. Both curves were generated by using standard linear regression analysis on SCSR performance comparison data. Because the SCSR's were tested at a constant oxygen consumption rate, capacity is defined as the product of oxygen consumption rate and duration. Capacity measures the amount of oxygen an SCSR can provide for escape purposes.

CONCLUSIONS

The comparison curves illustrate three important points: (1) Size and weight of SCSR's can be reduced by decreasing the oxygen capacity; (2) more efficient designs in terms of size and weight utilization are possible using current technology; (3) at an average oxygen consumption rate of 1.35 L/min, an 81-L apparatus would have a duration of 60 min. Reducing the oxygen capacity to 81 L would result in an SCSR at least 20% smaller than current apparatus, thus opening up the possibility of developing second-generation SCSR's, which could be worn by a miner as personal equipment.

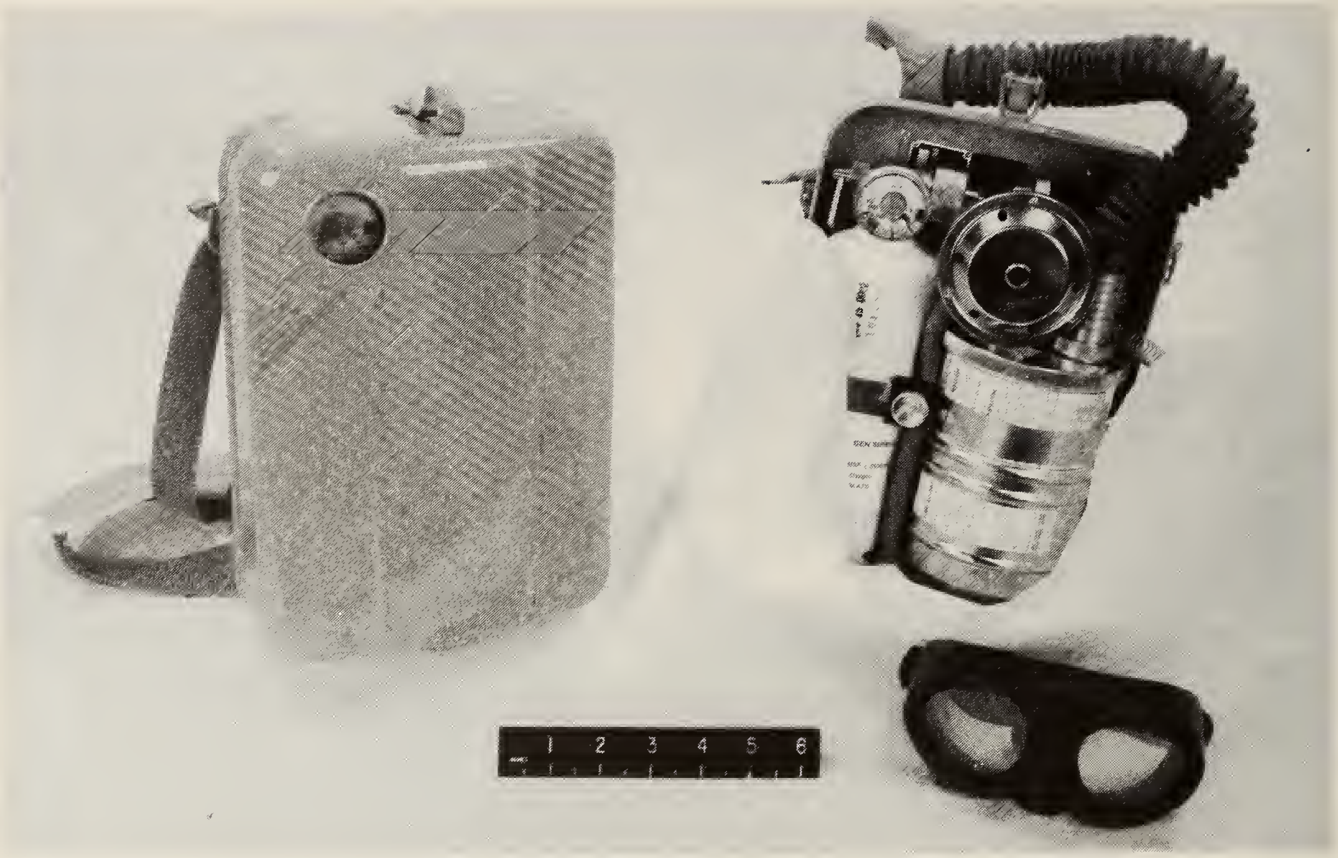


FIGURE 5.—CSE AU-9A1 in case and deployed.

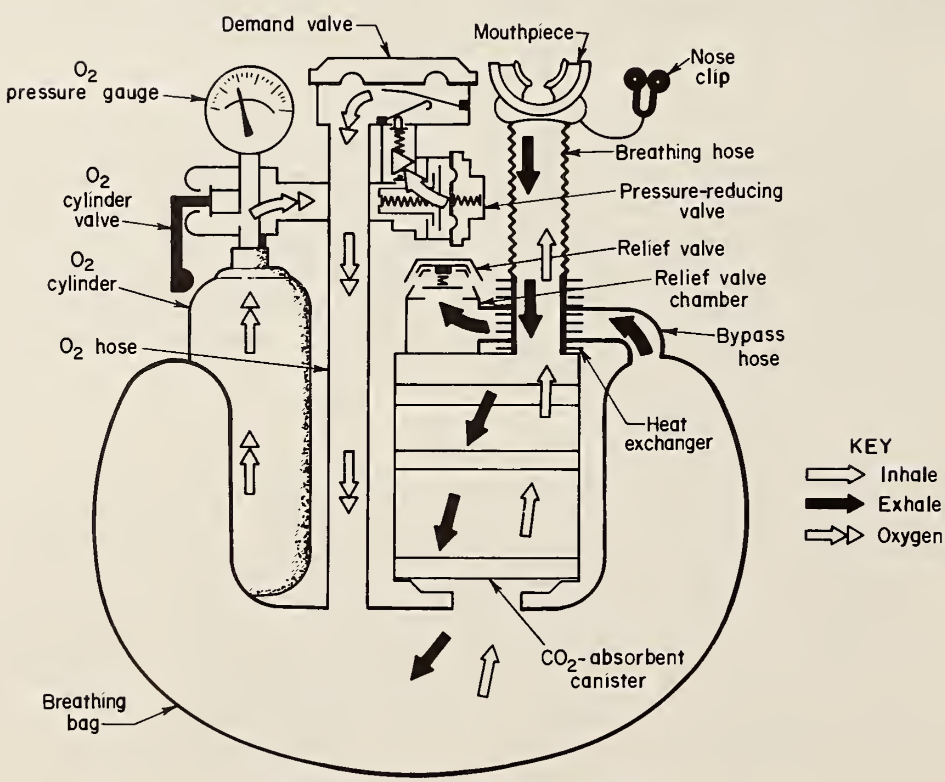


FIGURE 6.—CSE AU-9A1 schematic.

FIGURE 7.—Draeger OXY-SR 60B in case and deployed.

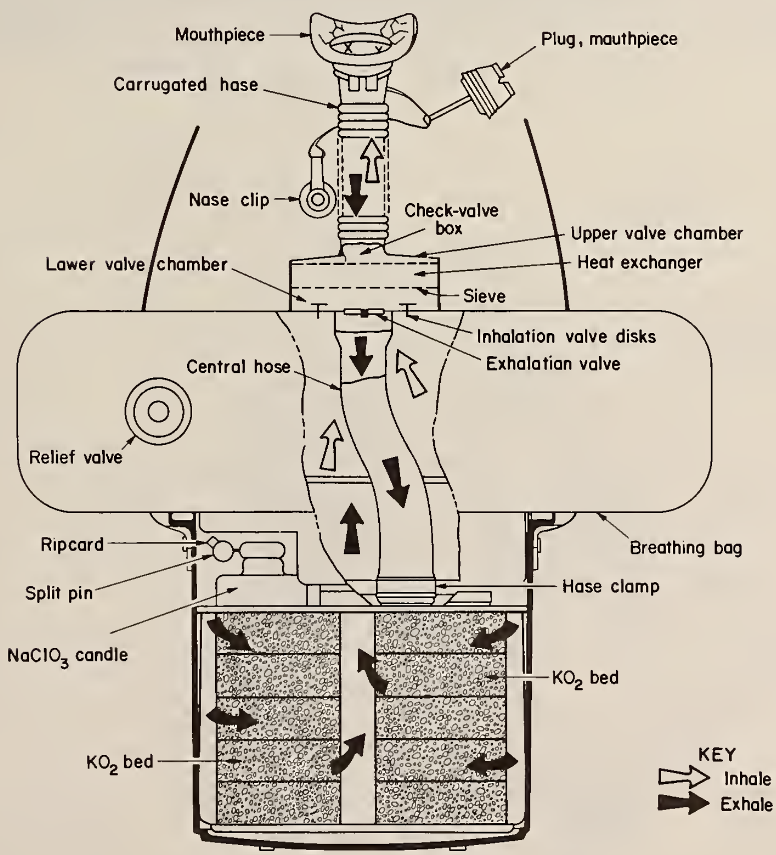


FIGURE 8.—Draeger OXY-SR 60B schematic.

FIGURE 9.—MSA 60-Min SCSR in case and deployed.

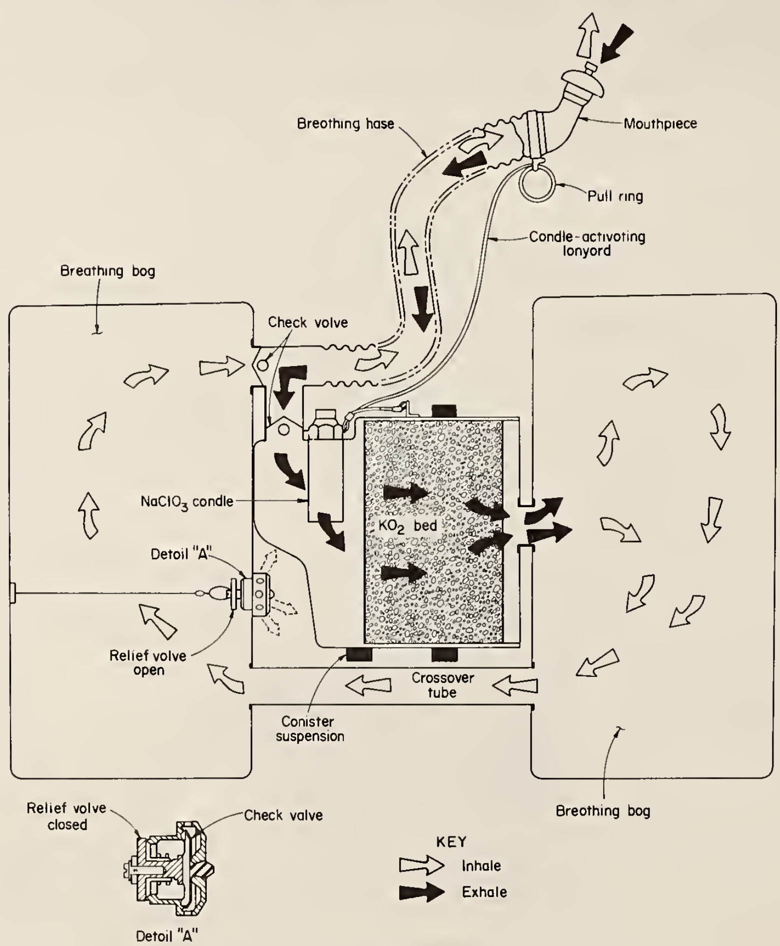


FIGURE 10.—MSA 60-MIN SCSR schematic.

FIGURE 11.—Ocenco EBA 6.5 in case and deployed.

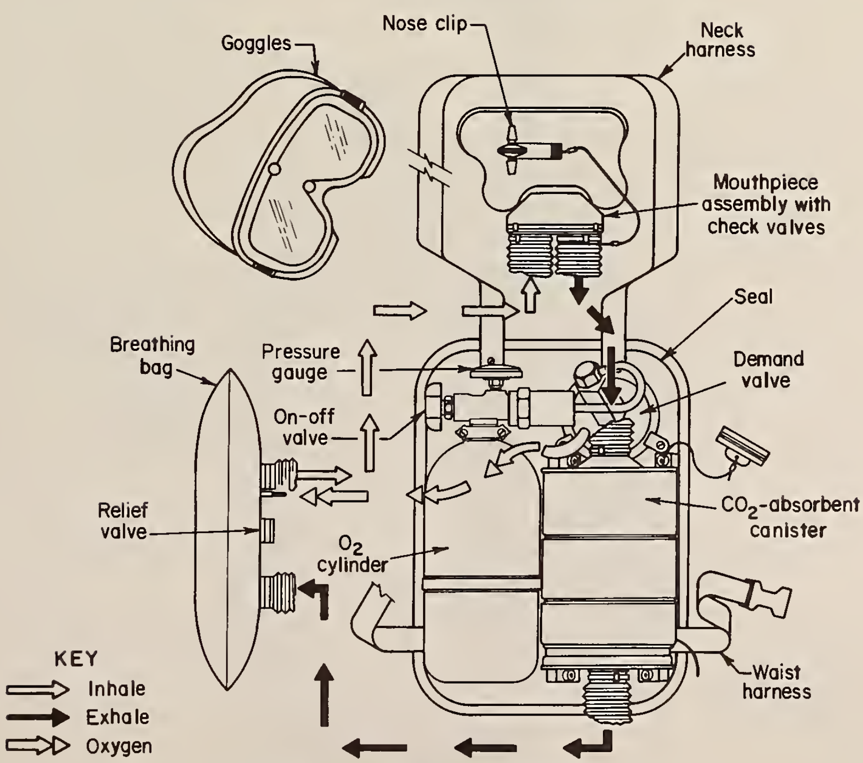


FIGURE 12.—Ocenco EBA 6.5 schematic.

FIGURE 13.—PASS 700 in case and deployed.

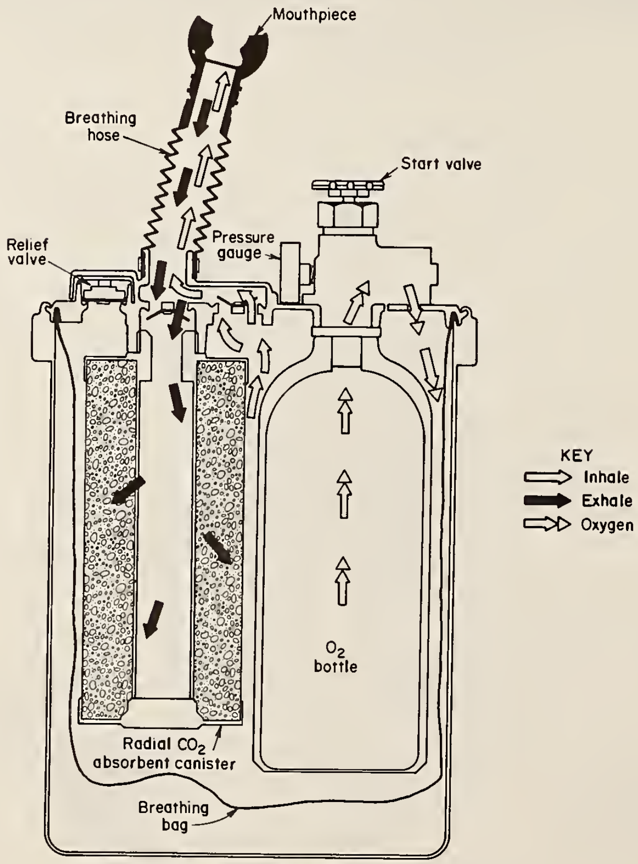


FIGURE 14.—PASS 700 schematic.

FIGURE 15.—USD SCEBA-60 in case and deployed.

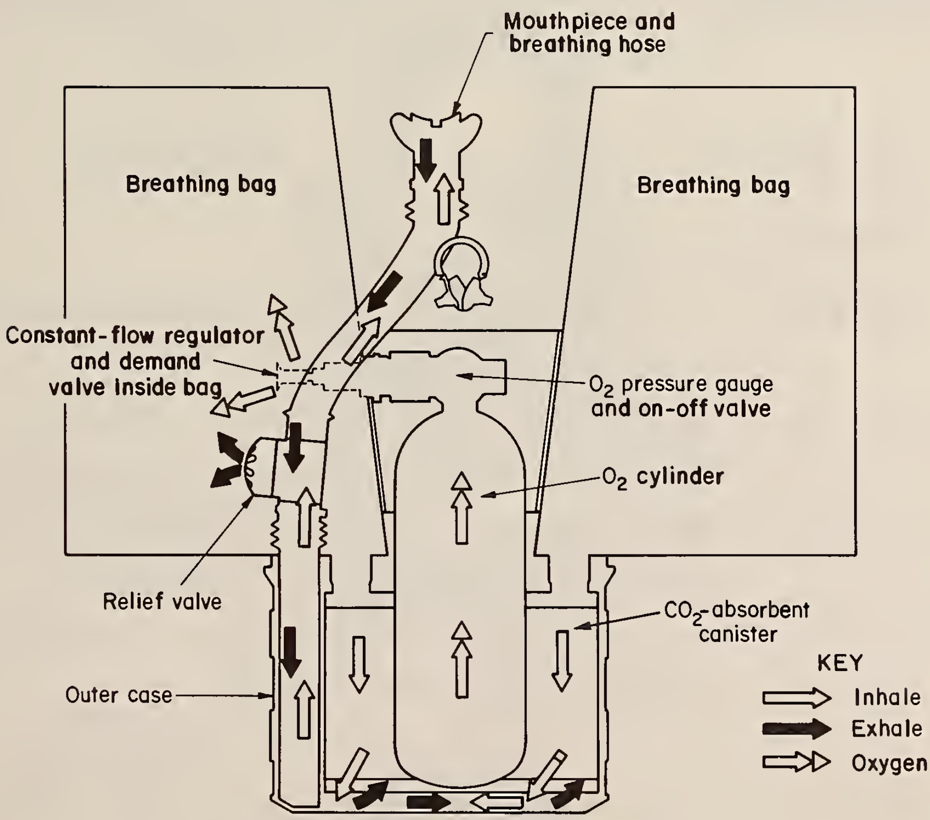


FIGURE 16.—USD SCEBA-60 schematic.

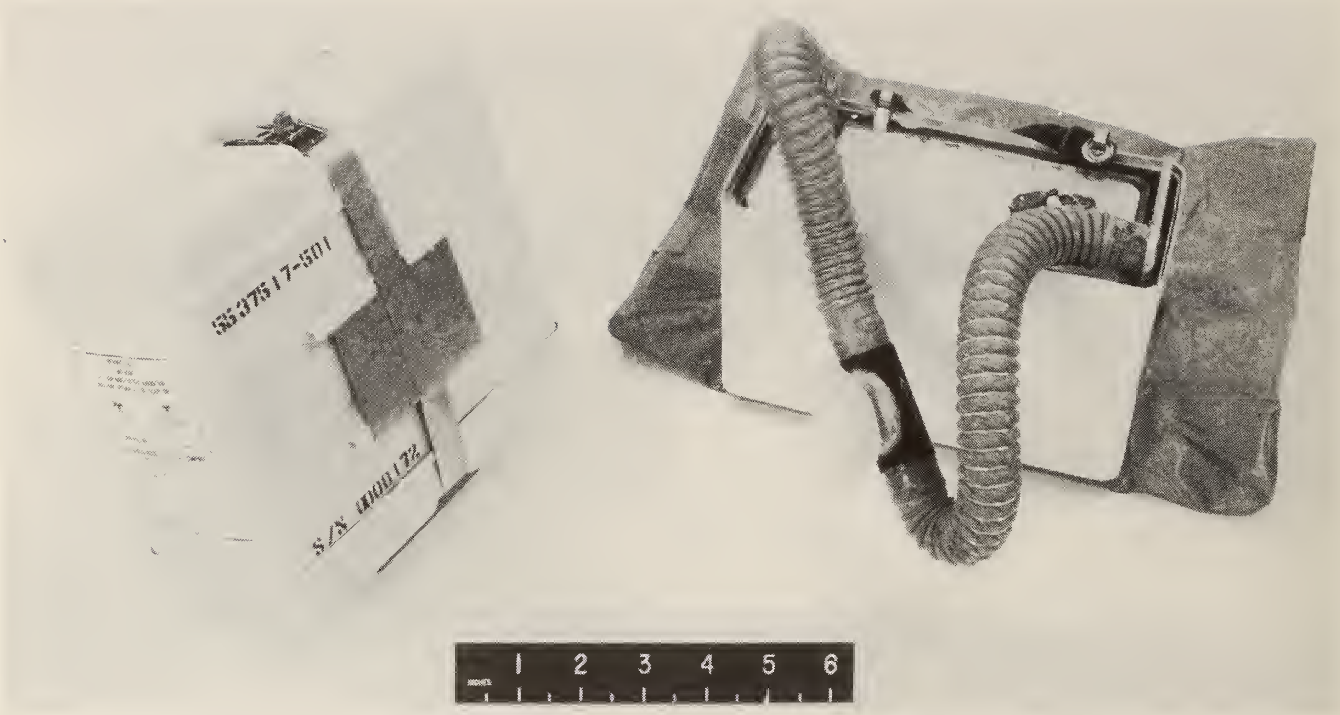


FIGURE 17.—Lockheed PBA in case and deployed.

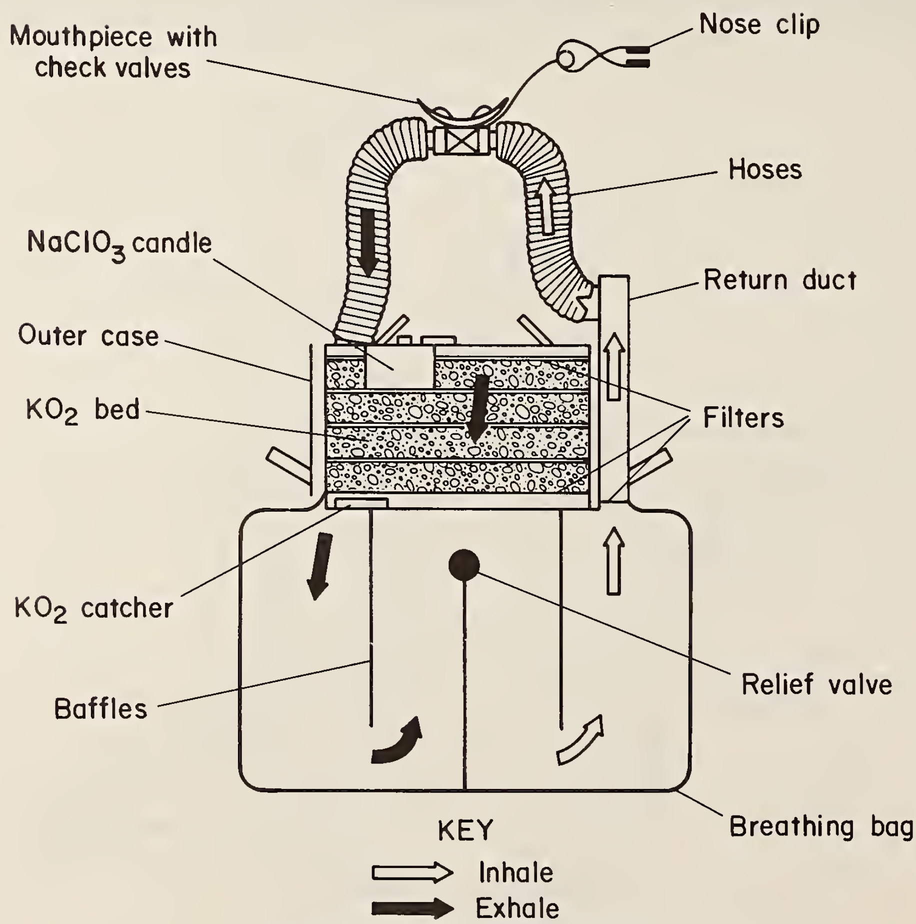


FIGURE 18.—Lockheed PBA schematic.

FIGURE 19.—MSA 10-Min PBA in case and deployed.

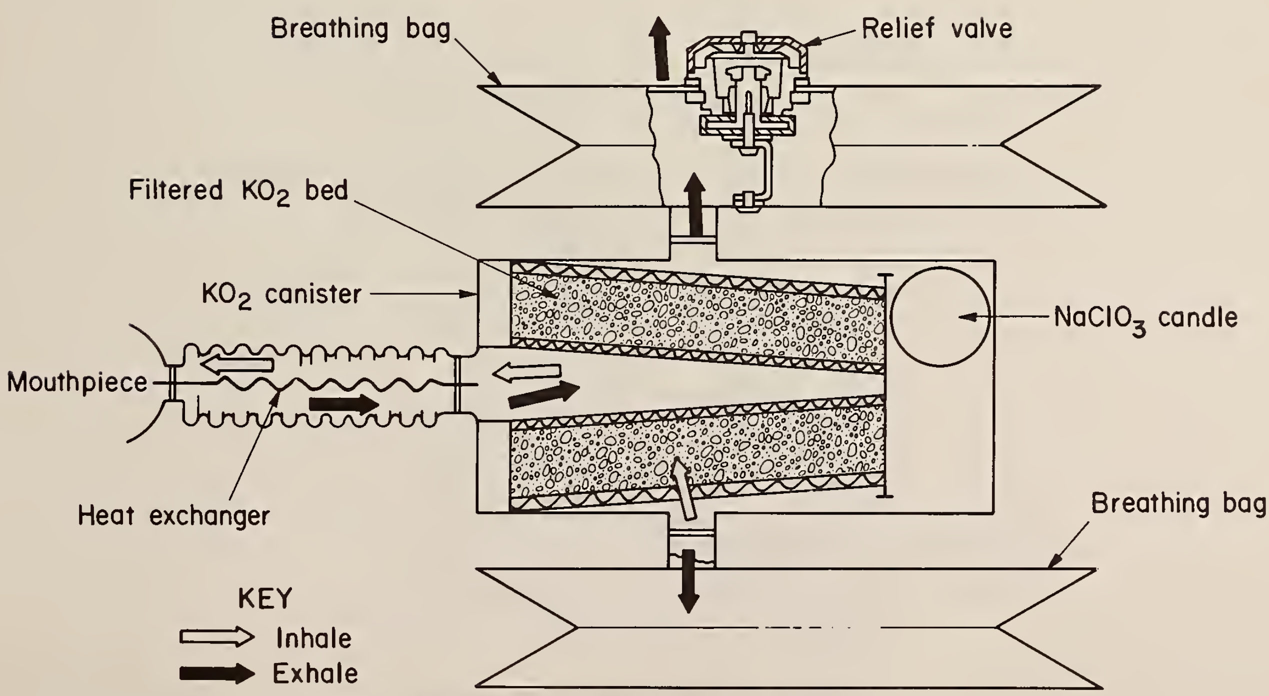


FIGURE 20.—MSA 10-Min PBA schematic.

FIGURE 21.—MSA 10/60 oxygen self-rescuer in case and deployed, and 60-min canister.

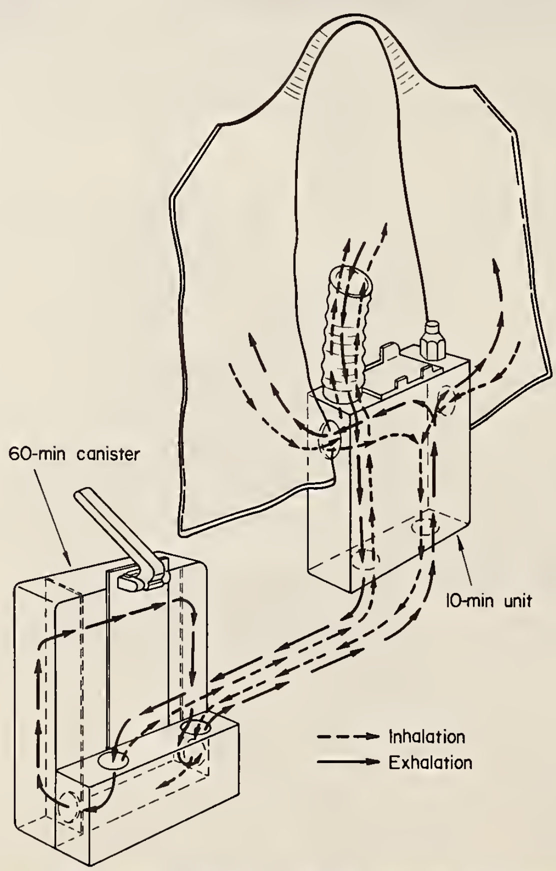


FIGURE 22.—MSA 10/60 oxygen self-rescuer schematic.

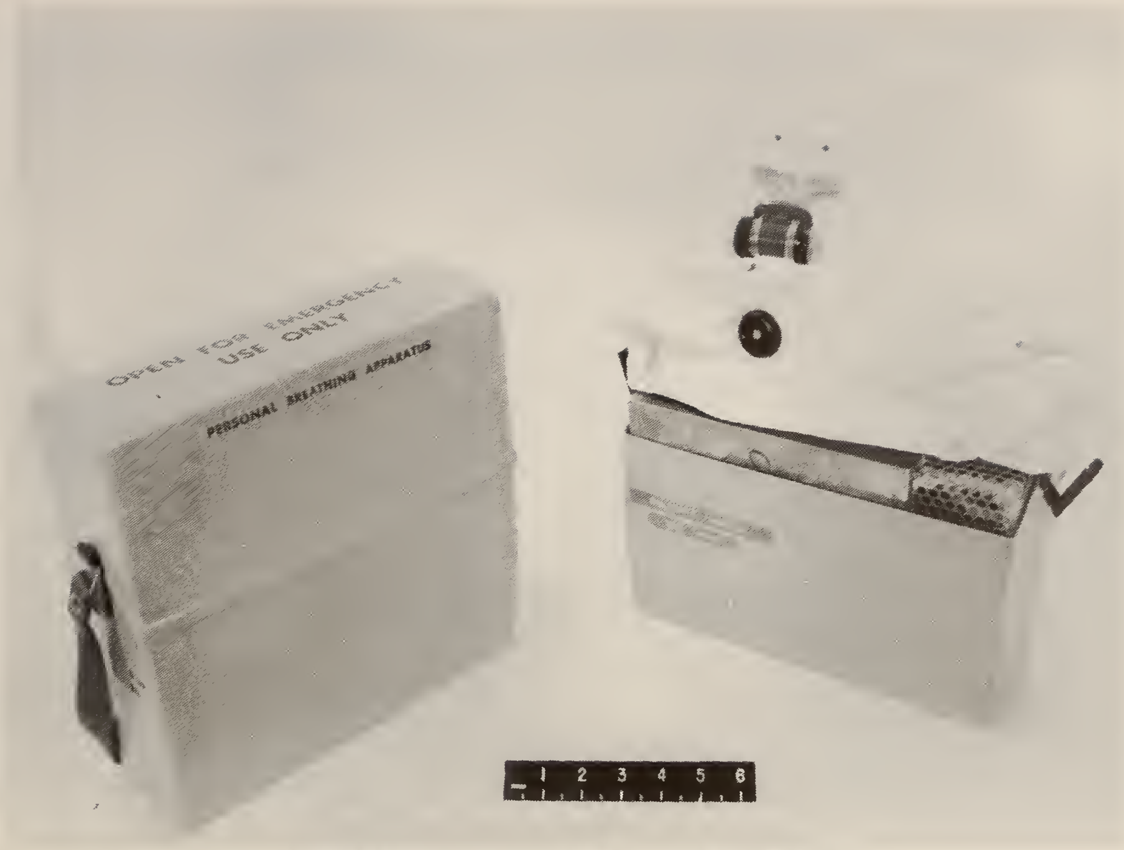


FIGURE 23.—Westinghouse PBA in case and deployed.

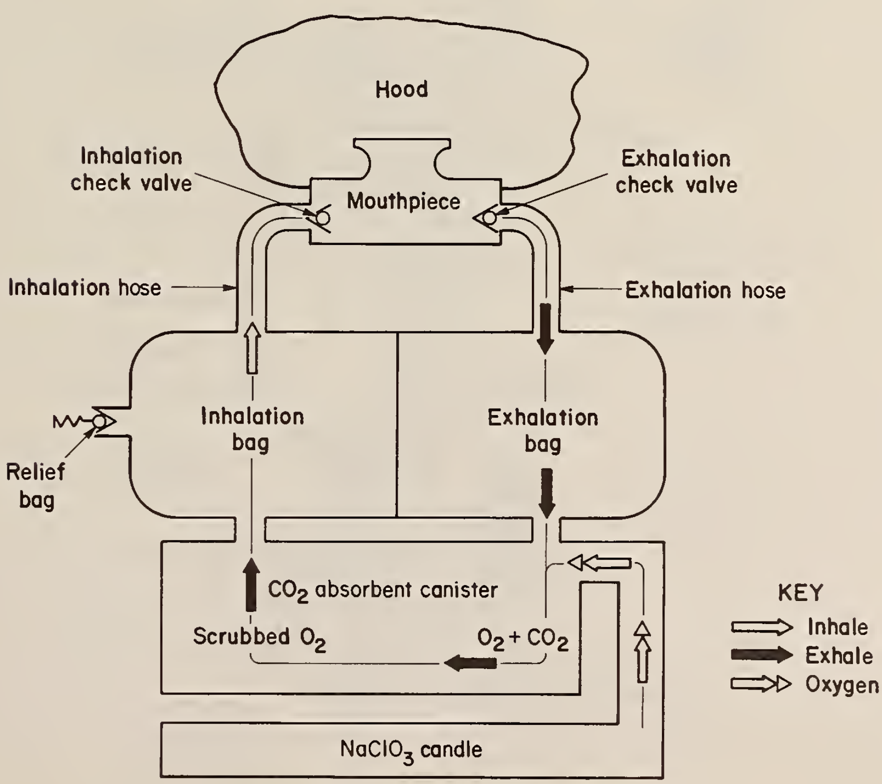


FIGURE 24.—Westinghouse PBA schematic.

FIGURE 25.—Auer SSR-90 in case and deployed.

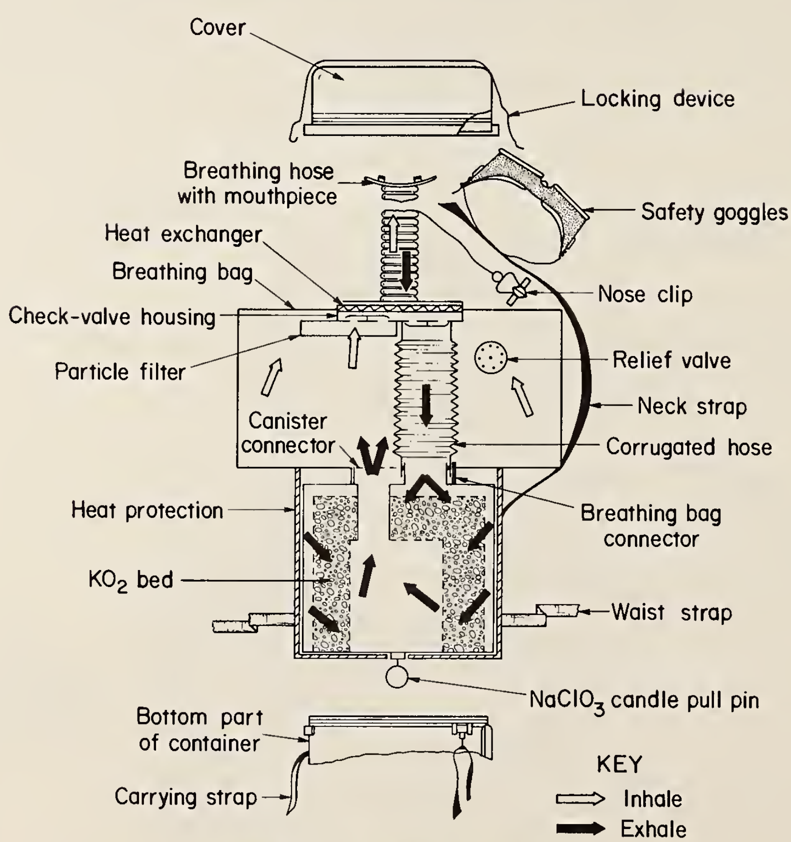


FIGURE 26.—Auer SSR-90 schematic.

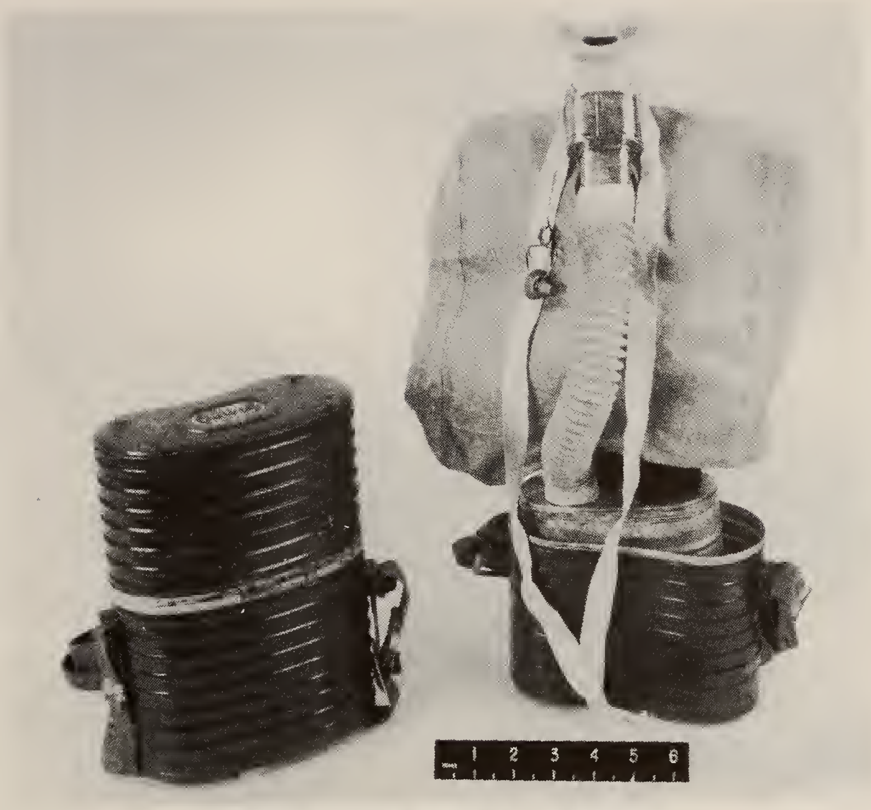


FIGURE 27.—AZG-40 in case and deployed.

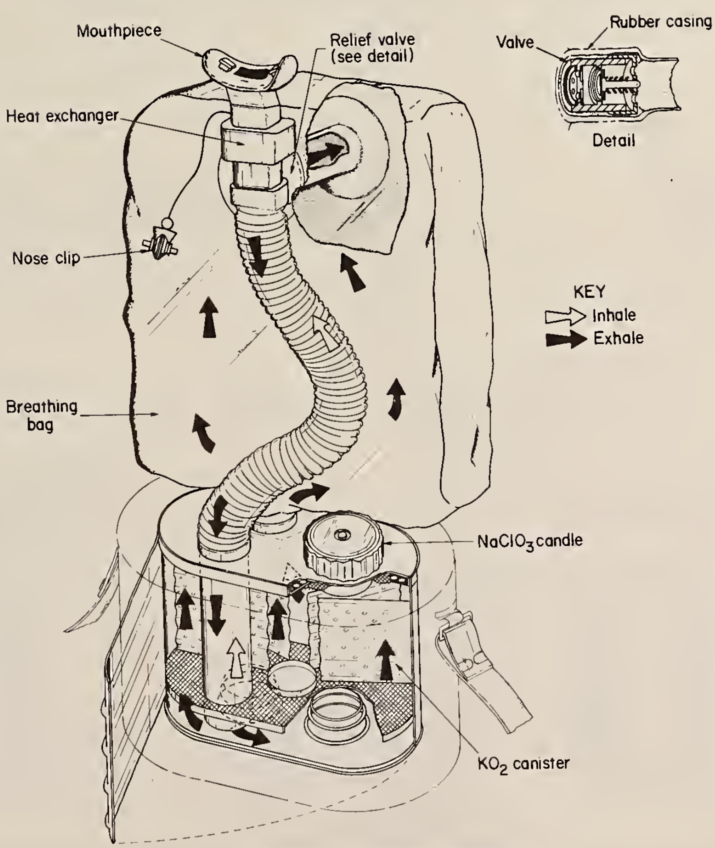


FIGURE 28.—AZG-40 schematic.

FIGURE 29.—Draeger OXY-SR 30 in case and deployed.

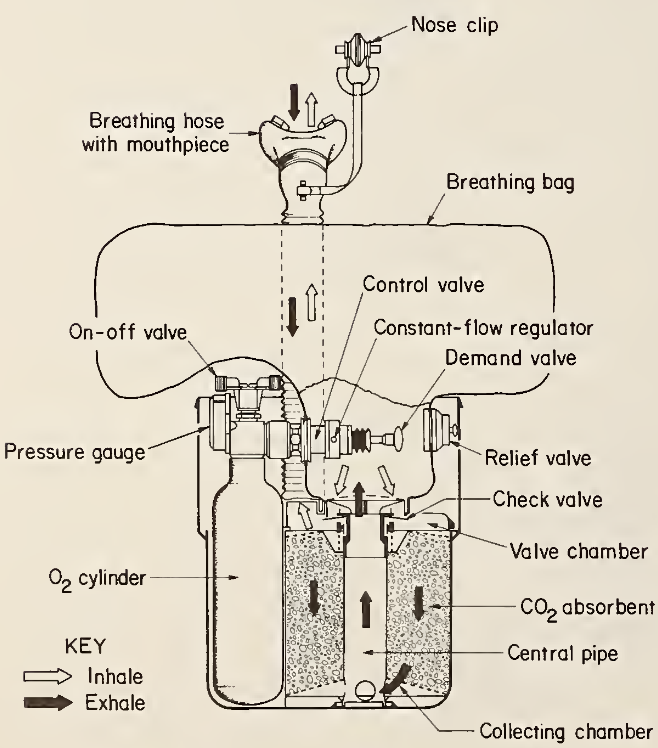


FIGURE 30.—Draeger OXY-SR 30 schematic.

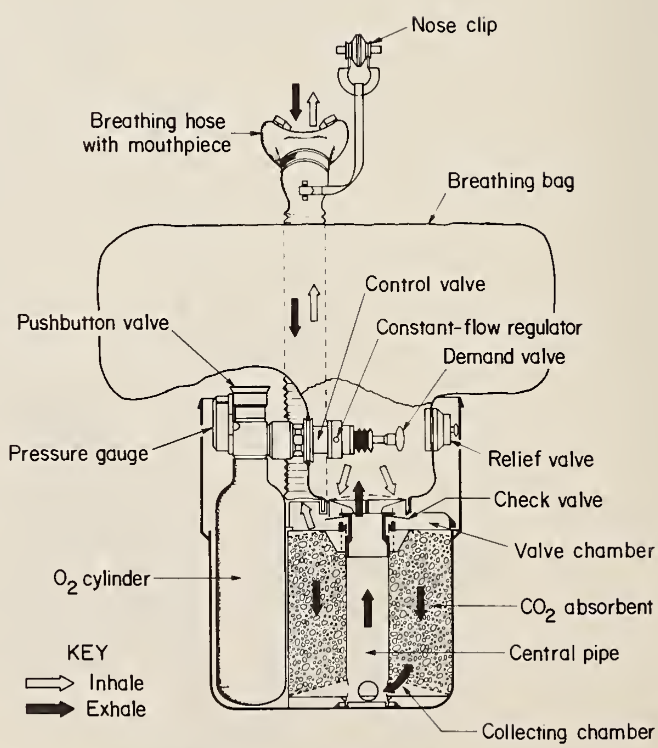


FIGURE 31.—Draeger OXY-SR 45 schematic.

FIGURE 32.—Fenzy Spiral II in case and deployed.

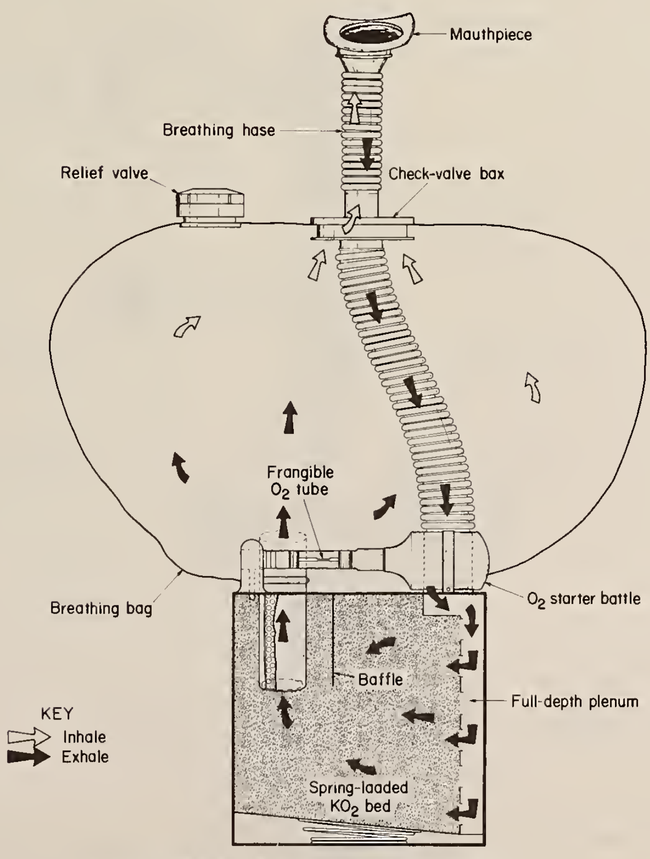


FIGURE 33.—Fenzy Spiral II schematic.

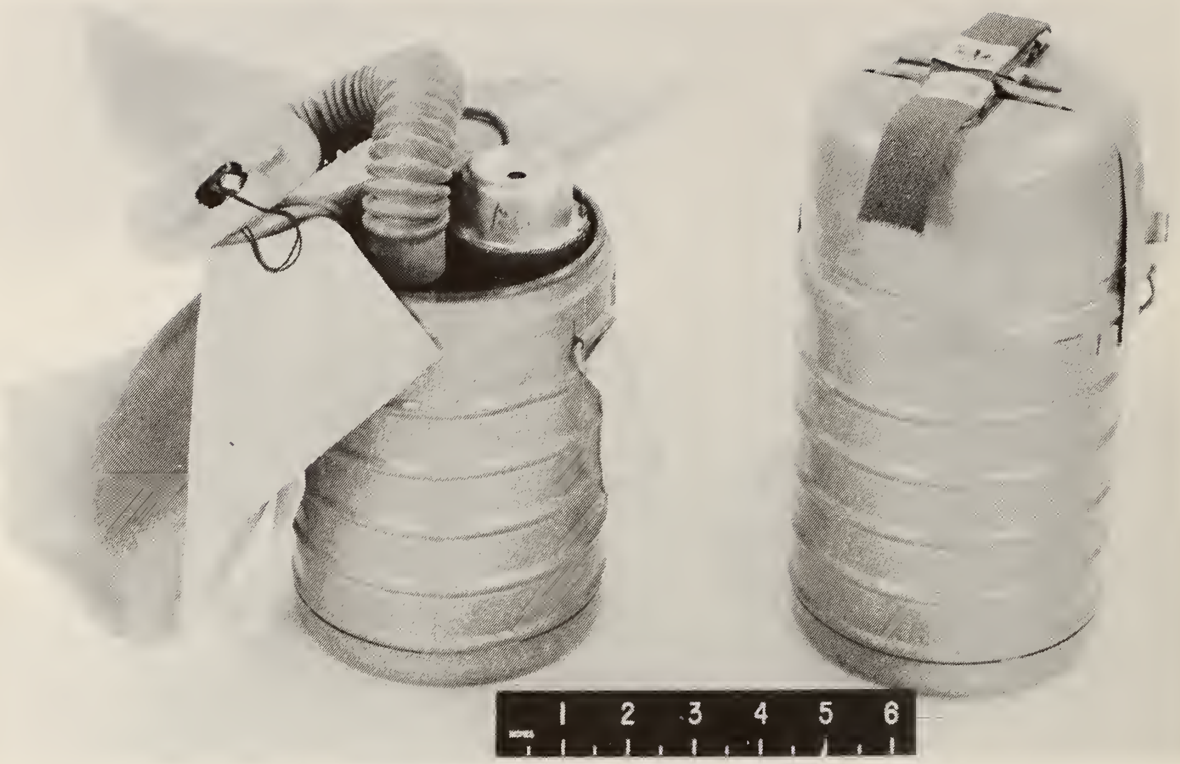


FIGURE 34.—WC-7 in case and deployed.

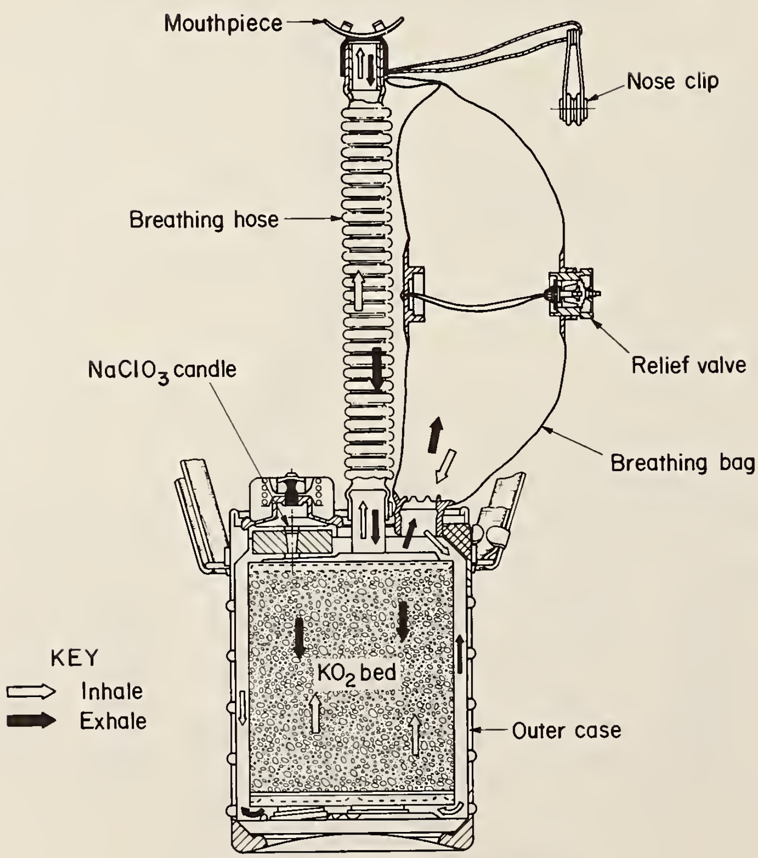


FIGURE 35.—WC-7 schematic.

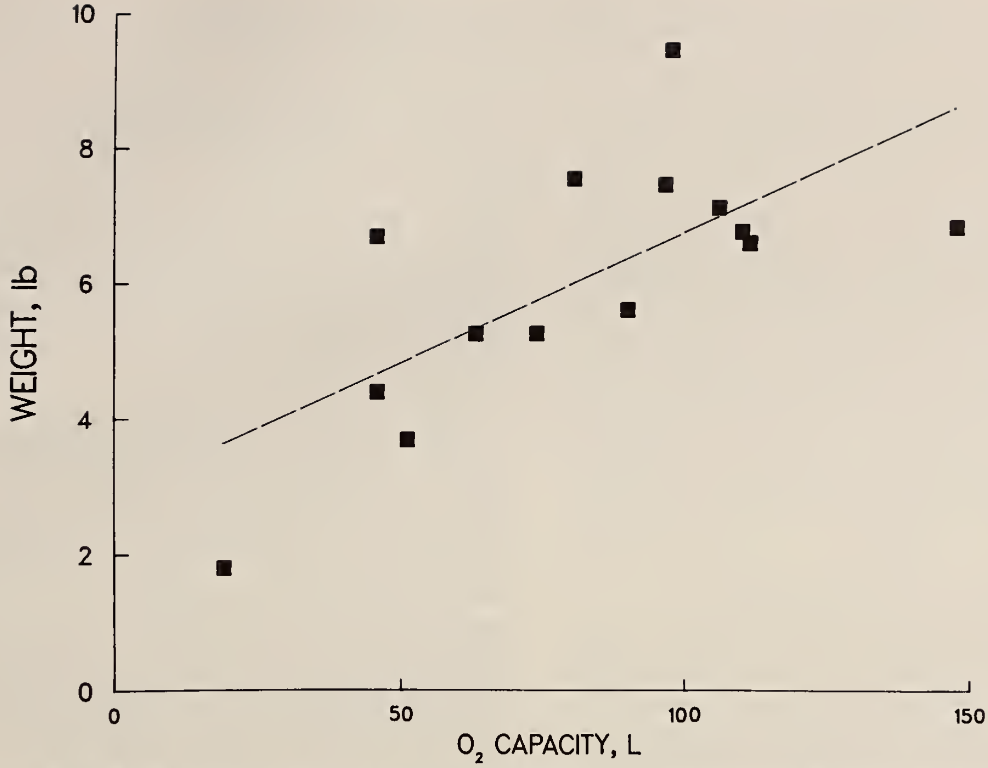


FIGURE 36.—Weight versus capacity comparison curve of self-contained self-rescuers generated from data compiled by the Bureau of Mines.

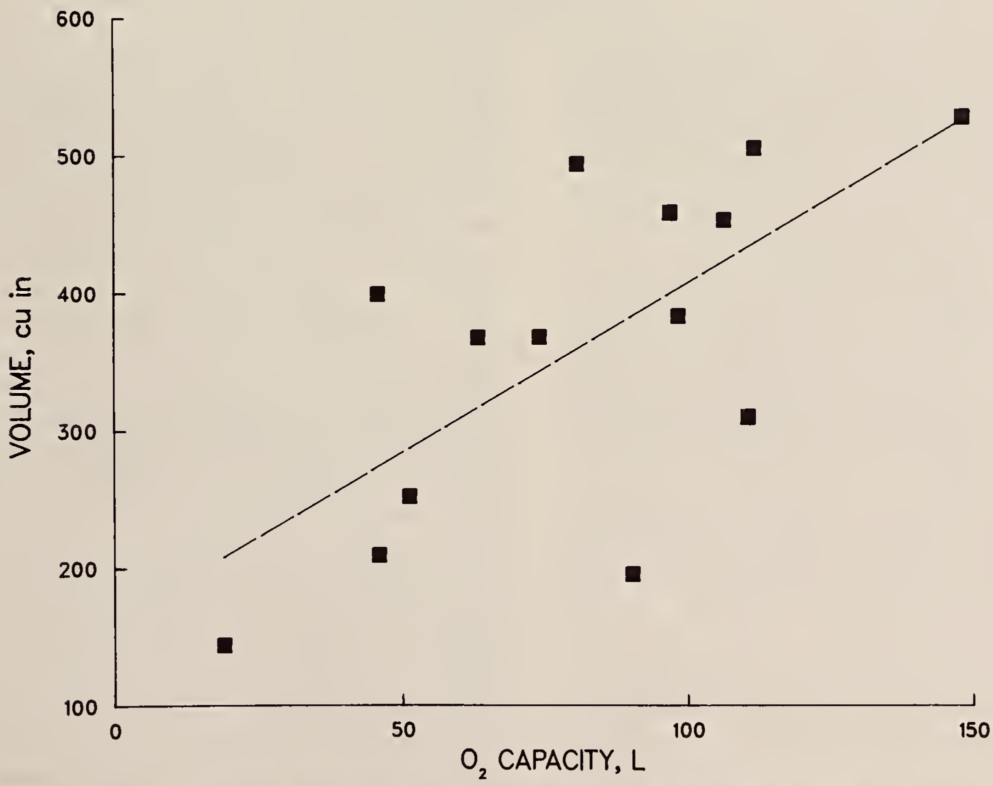


FIGURE 37.—Volume versus capacity comparison curve of self-contained self-rescuers generated from data compiled by the Bureau of Mines.

PROBLEMS IN DONNING SELF-CONTAINED SELF-RESCUERS

By Charles Vaught[1] and Henry P. Cole[2]

ABSTRACT

In 1986 University of Kentucky and Bureau of Mines researchers participated in a series of related SCSR donning studies. To establish a baseline for their investigations, they interviewed more than 50 mine safety instructors, rescue team members, and inspectors. The interviews support a widely held notion that very few underground coal miners ever actually don an SCSR in training. Rather, the typical training session will include a film, a slide-tape presentation, or a talk by an instructor who stands before the class and demonstrates the steps involved.

Given the industry's heavy reliance on abstract training methods, the research staff reviewed all generally available literature for the four models in common use (CSE, Draeger, MSA, and Ocenco). They targeted three main concerns with current training materials: (1) The recommended donning position appears difficult and inefficient and is impossible for miners working in low coal, (2) the donning sequence tends to place nonessential and time-consuming tasks such as strap adjustment ahead of some of the steps necessary to isolate one's lungs from the surrounding atmosphere, and (3) the materials present no simplified, easy-to-remember procedural rules to help miners order the complex array of tasks needed to use the device in an emergency.

An innovative training package was developed and field-tested. The data indicate that the new approach has great promise for improved SCSR donning efficiency.

INTRODUCTION

During 1986 researchers and technical staff from the University of Kentucky, the Bureau of Mines, the Mine Safety and Health Administration, the Kentucky Department of Mines and Minerals, and two coal companies conducted a series of related SCSR donning studies. Prior to this research there had been little systematic investigation of miners' ability to put the devices into use, although there had been many evaluations of SCSR durability, reliability, and duration of oxygen supply under various levels of physical exertion.

One exception found in the literature is the report of a field evaluation of the Draeger OXY-SR 60B and the MSA Model 464213.[3] Donning times for 46 miners were recorded and shown to range from 30 to 192 s. The average time for all subjects was 90 s. This report, although informative, does not indicate the frequency and types of donning errors, times for completion of part tasks, or whether the individuals were given assistance during their performance trials.

INITIAL AREAS OF CONCERN

To establish a baseline for the present studies, project researchers reviewed all available training materials dealing with the care and donning of the four SCSR models in common use (CSE, Draeger,

[1]Research sociologist, Pittsburgh Research Center, Bureau of Mines, Pittsburgh, PA.

[2]Educational pychologist, University of Kentucky, Lexington, KY.

[3]Peluso, R. G. Results from the Field Evaluation of Self-Contained Self-Rescuers. Paper in Proceedings of the 12th Annual Institute on Coal Mining Safety and Research, ed. by M. Karmis, M. H. Suthrland, J. L. Patrick, and J. R. Lucas. VA Polytech. Inst. and State Univ., Dep. Min. and Miner. Eng., Blacksburg, VA, 1981, pp. 125-131.

Ocenco, and MSA). They also interviewed more than 50 mine safety instructors, rescue team members, and inspectors. These individuals were asked to describe the performance capabilities of underground coal miners in using the devices. The preliminary inquiries suggested several actual or potential problem areas both in approaches to training and in actual performance. The most significant of these are discussed in the following sections.

Logical Problems With Existing Training Materials

The research staff targeted three main concerns with current training materials for donning SCSR's. First, the recommended donning position appears difficult and inefficient. It is impossible for miners working in low coal. Second, the donning sequence tends to place nonessential and time-consuming tasks such as strap adjustment ahead of some of the steps necessary to isolate one's lungs from the ambient atmosphere. Third, the materials present no simplified, easy-to-remember procedural rules that will help miners order the complex array of tasks needed to use the device in an emergency.

Generally, the available materials show an individual donning the SCSR while standing in a well-lighted room. The demonstrator first inspects the seals and pressure gauge and then performs those tasks necessary to allow him to work with the device while standing. Only then does he or she complete the steps needed to isolate the lungs from the surrounding atmosphere; the final critical task (putting on the nose clips, for instance) may be slotted as late as 10th in a sequence of 14 or more steps. Furthermore, in the materials it is not clear what is to be done with the cap and cap lamp. Some illustrations depict the cap without a lamp. Some show the demonstrator hanging the lamp cord around the neck, letting the cap and lamp dangle down the side. Still others seem to indicate that the individual removes and replaces the cap as he or she does steps that require the cap to be off.

In sum, these materials seem to advocate a training approach that is decidedly less than optimum for real-life conditions. An actual emergency might well entail a miner kneeling in a smoky entry in low coal where the only illumination would be that provided by his or her cap lamp. In such a predicament the SCSR would have to be donned quickly; it would have to be put on while working in an awkward position; and the lamp would need to be placed so that its beam could shine directly on the device. If one can imagine this situation, the value of a straightforward, easily remembered donning procedure and thorough hands-on training becomes readily apparent.

Lack of Hands-on Training

The interviews support a widely held notion that a majority of underground coal miners never actually don an SCSR. The typical training session will include a film, slide-tape presentation, or a talk by an instructor who stands before the training class and demonstrates the steps involved. Summary statistics for a series of mine trainer workshops conducted by Cole[4] revealed that the modal prior donning experience for individuals in most workshops was zero. This indicates there are a number of instructors teaching miners how to don the SCSR who have never themselves had one on.

The widespread lack of hands-on experience is a serious matter. There is a myriad of research to support the commonsense notion that lecture and demonstration do not constitute an effective means of teaching motor tasks. In the interviews, dollar costs were most frequently cited as the reason there is not more practice with the devices. The cost of using real SCSR's for the training of miners is approximately $400 to $600 per unit. Training models cost about the same. Thus, training facilities that

[4]See "Training in the Use of the Self-Contained Self-Rescuer," by H. P. Cole and C. Vaught, later in these proceedings.

have an SCSR for demonstration purposes rarely provide more than one.

A second factor often mentioned by the interviewees is the time required to train each individual on the apparatus. The session itself, with corrective instructions and practice, requires from 5 to 10 min per person. Sanitizing the mouthpiece and repacking the SCSR for the next trainee is reported to take an additional 5 to 10 min. With large groups of miners and limited time for training, these time requirements are seen as prohibitive.

Observed Motor Performance Errors

Six of the individuals interviewed had observed miners putting on one or more of four SCSR models and were able to provide impressionistic data about types of performance errors most commonly committed. In all cases reported, the units were being donned to carry out equipment reliability and duration studies, or for training purposes. The informants were asked to list the kinds of errors they witnessed and to comment on the ability of miners to put the devices into operation.

One mine safety instructor had recently carried out a hands-on exercise with the Ocenco EBA 6.5. The training was done with a total of 96 workers. These individuals were divided into groups of approximately 18 subjects. Each group was taken underground and given a 10-min demmonstration of the function, care, and use of the unit. Immediately following the demonstration the miners were selected nine at a time and placed near an overcast. Each person was given an SCSR. At a signal from the trainer all nine began to don the devices. The instructor observed and prompted the trainees during the process.

This informant agreed to rank observed errors according to frequency, but cautioned that mistakes he noticed with the first subjects were pointed out to miners in later groups before they could make the error. The trainer summarized his impressions as follows: (1) Most of the miners had the SCSR's on in approximately 1 min, but some required prompting for specific steps, (2) the most common error was failure to put on the nose clips—made by about one-fourth of the subjects, (3) approximately one person in each group of nine failed to put on the goggles, (4) slightly less than one person in each trial group had difficulty with the oxygen valve, (5) a few individuals put the neck strap over the lamp cord—this necessitated removing the SCSR and then the cap in order to put on the head strap, and (6) 2 out of the 96 had the bite lugs gripped in their incisors and the mouthpiece seal on the outside of the lips.

The other informants who had witnessed miners putting on SCSR's were less systematic in their recollections. However, they tended to agree that the most common problems were kinked air hoses, failure to put on nose clips, and omission of the goggles. It was also noted that trainees often did not follow the recommended sequence when donning the equipment.

None of these observations were based upon planned studies of performance. Therefore, little can be inferred about the optimal sequence of steps, the particular parts of the task most prone to error, or the effect of training. Yet this type of information is useful in developing a more systematic approach to donning the SCSR. It can reveal something about the parts of the task that are retained well and those that are not so well retained. It can be useful in designing controlled human performance studies such as the one conducted during the present research.

THE FIRST CONTROLLED DONNING ASSESSMENT

A coal company in eastern Kentucky participated in the initial study and furnished working models of the SCSR (the CSE AU-9A1) in use at its mines. The company trainers assisted in the design of the experiment, which is shown in table 1. Performance was observed under three trial conditions: (1) The baseline group (N=14) had no previous hands-on training with an SCSR, had never participated in a demonstration of an SCSR,

and had not received written or oral instructions about the device; (2) the control group (N=20) had hands-on training with the CSE 4 yr previously and at least one demonstration of the same model annually, the most recent having taken place 7 months prior to the study; (3) the treatment group (N=16) was identical to the control group in terms of previous experience except that they collectively received a donning demonstration immediately preceding their performance trial.

The tasks were administered individually in a specially arranged training room. Each person, wearing a miner's cap, belt, lamp, and filter self-rescuer (FSR), was brought into the room and asked to stand behind a line near the front wall. The SCSR was placed one case-length in front of the line with its bottom latch pointed toward the subject and the neck strap adjusted all the way out. The individual was given a standard set of instructions which stated the purpose of the study and requested him or her to put the SCSR on as if there were a fire. At a signal from the researchers the person began to don the unit. A video camera mounted on a tripod at the back of the room recorded the entire sequence. When the individual was finished, he or she took one step forward and raised the right arm. After the trial the person was shown the videotape, and all donning errors were corrected.

The purpose of the study was to compare the SCSR donning performance of the three groups. Differences in donning speed, proficiency, and errors could be related to no training (baseline group); initial hands-on training and annual demonstrations (control group); and initial hands-on training, annual demonstrations, and a recent demonstration (treatment group).

TABLE 1. - Treatment groups and conditions

Group	Baseline	Control	Treatment
Number (N).........	14	20	16
Underground miner..	No	Yes	Yes
Hands-on training..	No	Yes	Yes
Demonstration:			
7 months prior...	No	Yes	Yes
Immediately prior	No	No	Yes

It was assumed that the treatment refresher given by the company trainer would be based on the manufacturer's recommended sequence, as had all his earlier training. During the week in which the experiment was conducted, however, the trainer started to doubt the efficacy of the donning procedure he had been teaching. After consulting with a fellow instructor, he began to develop a simplified method designed to allow the miner to kneel and to isolate her or his lungs before completing secondary tasks. When it was time to give his demonstration to the treatment group, the trainer kneeled and performed the task using the new sequence. The procedure was not presented to the miners either visually or orally, because at that time it had not been formalized. This change in the training of the treatment group confounded the experiment. Observed differences in donning sequence, proficiency, and times could be caused both by recency of training and by change in approach. Nevertheless, much was learned from the study. Selected findings are discussed below.

Completion of Critical Tasks

There are three tasks that a miner must perform correctly in order to survive in a toxic atmosphere: (1) activate the oxygen, (2) insert the mouthpiece, and (3) put on the nose clips. This does not, of course, ensure that the SCSR is secured in a manner that will allow enough maneuverability for him or her to get out of a mine. Completion of the critical tasks should be regarded as an absolute minimum, therefore, not as a criterion for self-rescue and escape.

The individuals in the experiments were allowed all the time they wanted to complete the donning trial. The performance was stopped only when a person signaled that he or she was finished. Generally, the subjects believed that they had been able to isolate their lungs from the surrounding atmosphere and were prepared to travel through heavy smoke. As table 2

indicates, however, a majority of people in all three groups would probably have perished in an actual mine fire or explosion. This might be expected with naive individuals such as those in the baseline group, but those in the control and treatment groups were atypical in that they, unlike most miners, had had hands-on SCSR training and systematic annual demonstrations.

Inspection of table 2 shows that only 1 of the 14 subjects in the untrained group would have had a chance of surviving and he required approximately 95 s to complete the three critical steps. An important conclusion to be drawn from the performance of the baseline group is that the sequencing of steps necessary to don the apparatus proficiently is not well-cued by the equipment or by previously completed steps. Tasks that are not adequately cued are those most likely to be forgotten.[5]

Only 9 (56.25%) of the 16 miners in the treatment group were successful in doing the critical tasks. As can be seen in table 2, they tended to finish this part of the donning sequence more quickly than those in the control group. The shorter times required by these individuals are related to two factors which cannot be unconfounded. First, miners in the treatment group received a refresher demonstration only 2 to 4 h prior to their trial. Some of the increased speed with which they performed is probably due to this experience. Second, however, the procedure was changed by the instructor. Treatment group members were shown a new position (kneeling) and a new donning method that had them attempt the critical steps early in the sequence. The more rapid completion of these tasks by this group is due primarily to the second factor.

There is another element that has a bearing on the percentage of subjects in the treatment group who were able to complete the critical tasks. In the demonstration they were instructed to open the case on the floor, do the critical steps, slip the neck strap under and around the unit, and then don it. As was mentioned previously, in the experiment the SCSR was placed with the bottom latch toward the subject. Eight (50%) of the miners in the treatment group opened the case from the wrong end and proceeded to perform the critical tasks. When it was time to slip the neck strap under and put it on, they found they had the device turned backward. Several of them became confused and in trying to correct the error omitted one or another of the critical steps.

Given all the time they needed, 13 (65%) of the 20 individuals in the control group were successful in isolating their lungs. If they had had to do so within 1 min, however, only five (25%) would have survived. Members of this group were trained in the approved manner. In this procedure, adjusting the neck strap precedes and delays completion of the three critical tasks. Likewise, working in a standing position also makes it more difficult to open the case and complete the donning sequence. Many of the miners in the control group quickly gave up or did not attempt to don the head strap, adjust the neck strap, or tie the waist straps. Rather, a typical

[5]Hagman, J. D., and A. M. Rose. Retention of Military Tasks: A Review. Human Factors, v. 25, No. 2, 1983, pp. 199-213.

TABLE 2. - Number of persons completing the critical steps within specific time frames

Time frame, s	Group and number attempting		
	Baseline, 14	Control, 20	Treatment, 16
0-19	0	0	0
20-39	0	1	4
40-59	0	4	4
60-79	0	3	1
80-99	1	1	0
100-119	0	2	0
120-139	0	0	0
140-159	0	0	0
160-179	0	1	0
180-199	0	1	0
Total completing	1	13	9

response was to lift the SCSR up in one arm (usually crushing the breathing bag) and carry the unit with straps unadjusted and untied. Indeed, review of the videotapes reveals that the individuals in the control group were even less prepared for escape than were those in the treatment group.

Completion of Secondary Tasks

Some idea of the effect of the recent demonstration on performance can be gotten by inspecting table 3, which gives the percentage of each group completing each task. The miners in the treatment group were conscientious about attempting secondary tasks such as donning the head strap, putting on their goggles, adjusting the neck strap, and tying the waist straps. On average, the members of this group finished significantly more steps than those in the control group but spent no less time on the total trial (table 4). All in all, however, it must be concluded that both groups of trained miners generally lacked proficiency. They often made errors and interrupted tasks. Both groups required relatively long times to complete the secondary donning steps, as table 4 indicates. Most importantly, a sizable number probably could not have escaped a fire or explosion.

TABLE 3. - Percent of each group completing each task

	Group and number attempting		
	Baseline, 14	Control, 20	Treatment, 16
Case opened........	100	100	100
Oxygen on..........	50	95	88
Goggles saved......	86	75	88
Air hose extended..	100	100	100
Mouth plug pulled..	36	85	88
Mouthpiece inserted	93	95	100
Nose clip on.......	21	75	69
Head strap on......	57	80	81
Goggles on.........	64	60	100
Breathing bag open.	71	65	100
Neck strap on......	71	100	100
Hardhat on.........	50	65	94
Neck strap adjusted	7	25	100
Waist strap tied...	0	20	100

TABLE 4. - Mean times and standard deviations for persons completing critical and secondary donning steps, seconds

	Control group	Treatment group
Critical steps:		
Mean time.............	84.5	44.9
Standard deviation....	44.8	14.6
Secondary steps:		
Mean time.............	130.4	127.4
Standard deviation....	73.4	45.9
Total persons completing	13	9

SUBSEQUENT DONNING ASSESSMENTS

Insights gained from the first controlled assessment led the researchers to formalize a more logical donning position and a simplified procedure. Using this method, the miner in an emergency would take the SCSR from its storage box, kneel, and place the unit on the mine floor directly in front of his or her knees. He or she would then lay the hat on the mine floor so that the lamp could shine directly on the SCSR. After looping the neck strap loosely over the head, the miner would bring his or her face close to the unit and work with both hands to complete the following "chunked" sequence of steps: (1) activate the oxygen, (2) insert the mouthpiece, and (3) put on the nose clip. Doing these three things on the front end would rapidly isolate her or his lungs from a toxic mine atmosphere. The next tasks would be to (4) put on her or his goggles, (5) adjust both the neck and waist straps to place the SCSR close to chin and chest, and (6) replace the cap and move out.

This new approach is a generalized sequence which assumes the individual steps for implementing a particular model of SCSR have been demonstrated to and (ideally) practiced by miners in hands-on

training. What people forget is not how to do the discrete tasks. Rather, they tend to omit steps, or attempt them out of sequence. If miners were to be given a performance trial shortly after being trained in a 12- or 14-step donning procedure, they could be expected to jump around from task to task, to begin but not complete a step before starting on another, and to forget some steps entirely. In fact, the experimental data from the first donning assessment showed this to occur frequently.

It is much easier to remember to do tasks in their proper sequence if the entire process is placed in a simple, logical framework that organizes them all. The approach developed in this research serves that purpose. If a miner can remember the general steps given above, each one cues the recall of the tasks that are part of that step. addition, the simplified procedure helps the individual to order the overall sequence of donning tasks so that critical steps are done early and secondary ones later.

This donning method has been field-tested with approximately 16 groups of coal industry people in 3 States. Each group was given an explanation of the new donning position and the simplified sequence. The advantages of the procedure were explained, and then demonstrated by showing a 2-min videotape. The individuals next began actual donning trials. While one miner was putting an SCSR on, instructors and other group members were working in pairs to record the performance on a simple evaluation form.[6] The finished form provided a record of each person's donning sequence, time to completion of critical tasks, total time, and any errors made.

Table 5 provides summary data from 12 of these groups--5 for the Draeger, 4 for the Ocenco, 2 for the CSE, and 1 for the MSA. It is important to note that the

[6]See "Training in the Use of the Self-Contained Self-Rescuer," by H. P. Cole and C. Vaught, later in these proceedings.

TABLE 5. - Summary of data collected from SCSR donning workshops

SCSR type and site	Test date	Critical time, s			Secondary time, s			Prior donning[1]		Perfect donning sequence, % of total
		N	Mean	SD	N	Mean	SD	Mode[2]	No.[3]	
Draeger:										
E. Kentucky....	1/22	7	17.00	5.77	7	55.00	20.78	NAp	NAp	28.57
	1/28	27	23.89	10.61	27	64.70	29.08	3	12	62.96
	1/29	15	20.47	4.93	15	52.20	19.18	0	11	53.33
W. Kentucky....	3/18	16	16.25	4.97	17	41.12	17.09	0	6	22.22
	3/19	17	17.53	6.71	18	59.17	19.45	0	11	38.89
Ocenco:										
E. Kentucky....	1/22	11	26.27	5.87	11	79.45	26.16	NAp	NAp	63.64
	1/29	11	33.73	10.00	11	82.45	24.11	0	9	45.45
W. Kentucky....	3/18	16	26.44	5.66	15	69.06	25.42	0,1	3,3	[4]11.76
	3/19	17	38.64	11.10	19	84.32	19.08	0	16	47.37
CSE: E. Kentucky	1/22	9	21.67	4.77	9	68.88	17.95	NAp	NAp	66.67
	1/29	16	24.94	11.39	16	62.44	20.91	0	9	64.71
MSA: E. Kentucky	1/29	10	17.90	5.15	10	51.50	14.35	0	8	50.00

NAp Not applicable. [1]Experience with this model.

[2]Mode = most frequent occurring value in a set where different values may occur more than once.

[3]No. = number of people who gave the modal response for their group.

[4]Of the 17 trainees, 9 adjusted the straps before donning their goggles. Although this deviates from the perfect sequence, it is not a critical error.

TABLE 6. - Mean times and standard deviations for critical and secondary donning tasks by type of SCSR[1], seconds

	Draeger	Ocenco	CSE	MSA
Critical tasks:				
Mean time.........	20.47	33.73	24.94	17.90
Standard deviation	4.93	10.00	11.39	5.15
Secondary steps:				
Mean time.........	52.20	82.45	62.44	51.50
Standard deviation	19.18	24.11	20.91	14.35

[1]For classes conducted 1/29/86.

data represent the first hands-on SCSR experience for most of these people. Therefore, the performance results must be related to instructional procedures rather than to practice with the units. Some of the more intriguing findings are discussed in the following sections.

Completion of Critical Tasks

Inspection of the mean donning times for critical tasks suggest that the simplified procedure results in more rapid completion. In addition, an examination of the evaluation forms revealed that the performance also tended to be smoother than the trials of the subjects in the initial study. There were fewer task interruptions, and most steps were done in the proper sequence. Very few errors were made in completing the three critical steps.

Table 6 shows the means and standard deviations of the critical task completion (part) times recorded for the CSE group whose trial occurred on January 29, 1986. Comparison of these values with those in table 4 reveals that the new approach has great promise in improving SCSR donning efficiency. Even the mean time (44.9 s) for completion of critical steps required by miners in the initial treatment group far exceeded the average of those in the CSE group of January 29, 1986. Since both of these groups had had the new position and simplified sequence demonstrated to them, these large differences are undoubtedly due to the improved and more explicit instruction developed after the first experiment.

Completion of Secondary Tasks

Using the same two groups to compare overall proficiency is also encouraging. Their difference in mean total donning time (127.4 versus 62.4 s) is even greater than their difference in average time needed to do the three critical tasks. In addition, as can be seen in table 5, the percentage of those who turned in a perfect trial with the CSE's on January 29, 1986 (64.71%) is higher than the percentage of initial treatment group members who were able to meet the absolute minimum for survival (56.25%).

DISCUSSION

The complexity of existing instructional approaches, combined with the infrequency of hands-on training, contributes significantly to miners' difficulties in getting the SCSR on flawlessly and rapidly. The research reported in this paper suggests a more efficient donning procedure. The data contained in table 5, especially the percentages of each group having a perfect sequence on the first trial, are encouraging. Much remains to be done, however.

Two important issues have not been addressed in these or earlier studies. First, it is not known how well or how long miners retain their skills in donning SCSR's. The optimum training necessary to achieve and maintain high levels of proficiency needs to be empirically determined. Then, recommendations to the

industry can be made based on an understanding of what constitutes an effective and valid approach. Second, the present research has identified donning tasks that are time-consuming, are difficult to perform, and/or result in frequent errors. This information can assist in the improvement of SCSR designs. Well-controlled human performance studies of equipment design changes can reveal which modifications optimize miners' donning capabilities. Continued investigation of problems in implementing the self-contained self-rescuer may well help to prevent future tragedies.

PHYSIOLOGY OF MINE ESCAPE: PERFORMANCE DECREMENTS DUE TO RESISTANCE BREATHING DURING THREE EXERCISE PROTOCOLS

By Kurt Saupe[1] and Eliezer Kamon[2]

ABSTRACT

In the event of a mine fire or explosion, an irrespirable atmosphere is formed and self-contained breathing apparatus are necessary to support life. An ideal breathing apparatus would simulate ambient air in every way; however, this has not been achieved in any type of portable apparatus. Apparatus that are used for escape are best when light in weight and small in size. Small size and light weight, however, usually result in apparatus that are physiologically stressful in other ways. The most common stressors of concern are levels of CO_2 and O_2, temperature, and breathing resistance. From research being conducted at the Noll Laboratory for Human Performance Research, it has been found that breathing resistance can significantly affect performance in a number of areas. One significant finding is that a given level of breathing resistance may negatively affect escape speed if the speed is high and yet not affect escape at a lower escape speed. Three exercise protocols were performed to study effects on maximum attainable oxygen consumption rate and, thus, escape speed. It was found that the higher the exercise intensity, the greater the negative effect of a given breathing resistance.

INTRODUCTION

To fulfill all the potential needs of a worker, a respirator should not limit the worker's performance under a wide range of conditions. Some of these conditions include low-intensity steady-state exercise, short-duration high-intensity exercise, and gradually increasing work to ventilatory exhaustion. These three conditions place different demands on respirators. Resistance is the stressor that seems to have the greatest effect on the standard measures of performance, such as maximum attainable speed of travel. This is probably due to the lower attainable ventilation rate, and consequently, lower attainable oxygen consumption rate, so that the worker is forced to slow down. Conclusions about the amount of resistance that can be tolerated before a performance limitation is seen may well be different depending upon the intensity of exercise used to evaluate the resistance.

The purpose of this investigation was to quantify the performance decrements caused by resistance breathing during a simulated coal mine escape. Since there is no one protocol that adequately simulates all the possible scenarios that might be encountered during an emergency mine escape, three different escape protocols were examined. These three protocols were chosen both to represent a wide range of demands on the respirator and to give insight into the physiological mechanisms responsible for the performance decrements. The three protocols used were--

1. A 2-mile run for time at a maximum (variable) self-paced speed.
2. A progressive exercise test to exhaustion.
3. An hour-long walk at the maximal speed-grade combination (fixed) that could be maintained for the hour.

[1]Graduate student.
[2]Professor.
Penn State University, Noll Laboratory for Human Performance Research, University Park, PA.

EXPERIMENTAL DESIGN AND TEST METHODS

SUBJECTS

Male subjects were recruited from the Penn State University area. Subjects were either undergraduates, graduate students, or staff of Penn State. Different subjects were used for each of the three protocols with some subjects taking part in both the hour walk and progressive exercise tests. Subject characteristics are listed in table 1.

METHODS

The physiological variables of heart rate, ventilation rate ($\dot{V}E$), fraction of expired O_2 (FEO_2), fraction of expired CO_2 ($FECO_2$), and pressure at the mouth were continuously measured and recorded on-line via a PDP-11 (or PDP-8) computer and in-house software. From these variables, rate of O_2 consumption ($\dot{V}O_2$), rate of CO_2 production ($\dot{V}CO_2$), respiratory quotient (R), and $\dot{V}E/\dot{V}O_2$ were continuously calculated.

The inspired and expired resistances were caused by inserting a small-diameter, 5-cm-long tubing segment in both the inspired and expired sides of the data collection system. The resistance of the system without these restrictive segments was 1.5 cm H_2O at 120 L/min.

PROCEDURES

Maximal aerobic capacity was measured using a separate progressively graded treadmill exercise test to exhaustion, as part of a preliminary medical examination.

The short-term exercise called for 2.5% increases in the grade of the treadmill every 4 min. The data over the last minute of exercise at each grade were used to represent the steady state value for that exercise intensity.

The prolonged exercise was performed at the maximum speed and grade that could be maintained for 1 h by the subject. One hour of exercise was first performed without resistance to breathing; the exercise was repeated next with a randomly selected resistance to breathing. If 1 h of exercise could not be accomplished, the subject returned on another occasion to attempt the same resistance at an exercise intensity obtained by a reduction in the grade of the treadmill. This was repeated until the hour of exercise was completed, and that exercise intensity was considered the highest sustainable for the given resistance.

The 2-mile runs for time were performed so that subjects had a visual display of how far they had run. Subjects were able to control their speed by giving a thumbs-up or thumbs-down to an investigator who was sitting at the treadmill control panel. Four, all-out 2-mile runs were initially done by each subject with no resistance to establish a reliable baseline. When these runs were completed, subjects ran a low-resistance (10 cm H_2O at 120 L/min) and a high-resistance (34 cm H_2O at 120 L/min) all-out 2-mile run in a randomly assigned order. These self-paced, all-out runs were performed a week apart to minimize any training effect.

TABLE 1. - Mean subject characteristics

(Standard deviation in parentheses)

Exercise protocol	N	Age, yr	Height, cm	Weight, kg	$\dot{V}O_2$ max, L/min
Short-term progressive	5	26 (2)	177 (8)	72 (9)	3.95 (0.77)
1-h walk..............	7	26 (4)	178 (7)	75 (10)	3.77 (.56)
2-mile run............	5	24 (3)	178 (4)	73 (9)	4.20 (.60)

RESULTS

The problem of how to best quantify the resistance-induced performance decrements so that they could be compared across all three protocols was addressed by expressing the $\dot{V}O_2$ that could be maintained during a resistance trial as a percentage of the $\dot{V}O_2$ that could be maintained during a no-resistance control trial. If, for example, a subject could maintain a $\dot{V}O_2$ of 4 L/min during a no-resistance 2-mile run and a $\dot{V}O_2$ of 3 L/min during a 2-mile run with a resistance of 34 cm H_2O at 120 L/min, the performance decrement would be expressed by stating that he or she could maintain a $\dot{V}O_2$ of 75% of the control value with the 34-cm H_2O at 120-L/min resistance. These data suggest that as the task performed by the subject becomes increasingly difficult (higher percentage of $\dot{V}O_2$ max), the performance decrement that one sees with a given resistance becomes greater. Figure 1 shows the

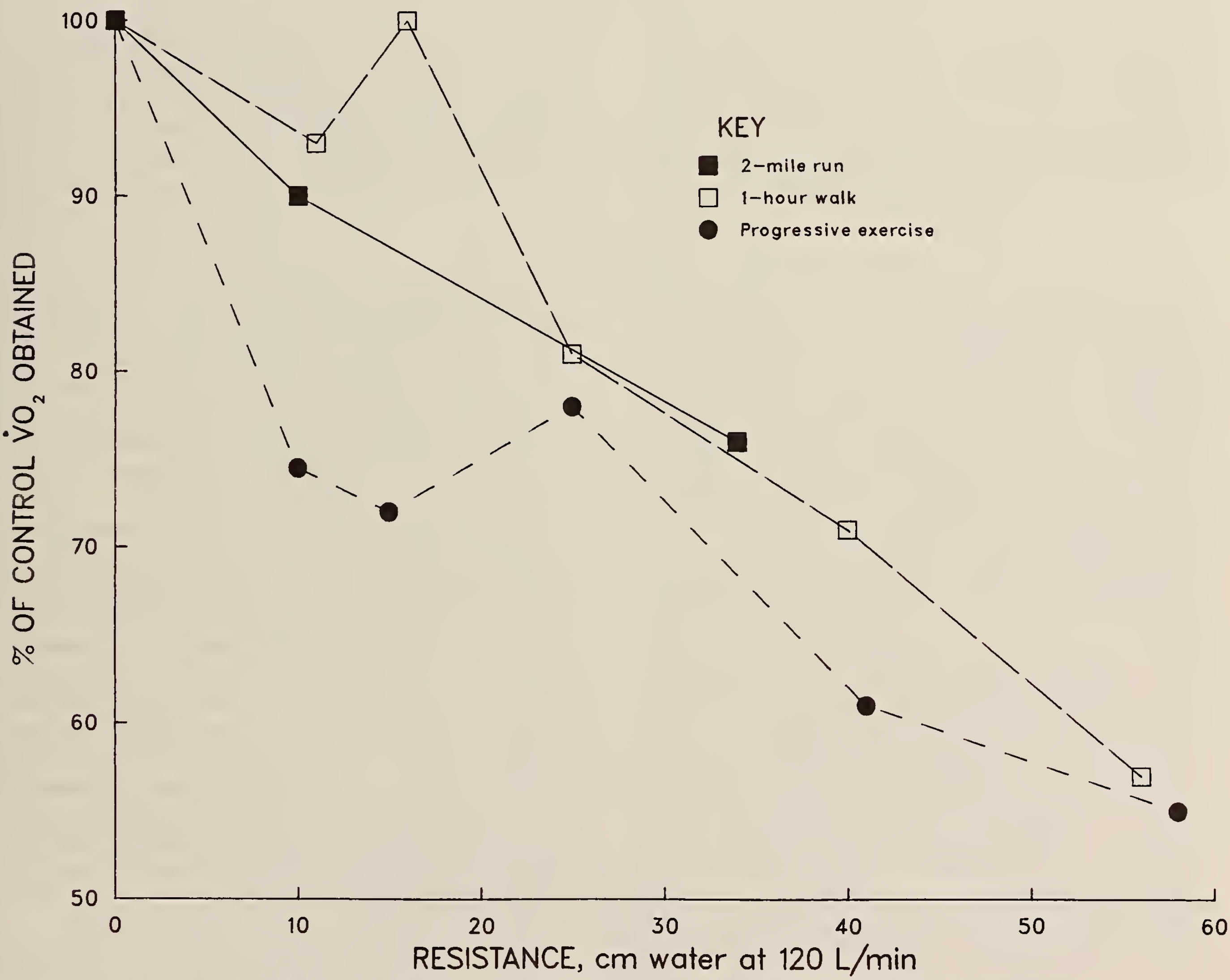


FIGURE 1.—Percent of control $\dot{V}O_2$ obtained versus breathing resistance for three exercise intensities.

percentage of a control trial $\dot{V}O_2$ that could be maintained over a range of resistances for the three protocols. The somewhat nebulous term "maximal maintainable $\dot{V}O_2$" was defined differently for each of the three protocols. For the progressive exercise test, this term was defined as the $\dot{V}O_2$ at the highest obtainable exercise intensity. For the hour-long walks it was defined as the mean $\dot{V}O_2$ between minutes 15 and 45. For the 2-mile runs it was defined as the mean $\dot{V}O_2$ from minute 5 to the end of the 2 miles.

DISCUSSION

These data illustrate a principle that is often overlooked when one looks at the level of breathing resistance allowable in a specific breathing apparatus. This principle can best be illustrated by imagining what would happen to an individual whose only source of air was through a soda straw. The individual would be able to perform tasks such as reading and writing with no noticeable performance decrement. If the individual were asked to perform tasks of increased physical demand, he or she would find that the more strenuous the task (in terms of $\dot{V}O_2$ required), the more he or she was encumbered or restricted.

Any standard or specification defining the maximum allowable resistance to breathing of a respirator should be specific to the intensity of physical activity that the users of this respirator are expected to maintain.

CONCLUSIONS

Breathing resistance levels that significantly impair performance at a maximal work intensity may not impair performance at a lesser work intensity. Breathing apparatus that are designed to be used at low or medium work intensities, therefore, might be permitted to have higher breathing resistance levels than apparatus that are expected to be used at high work intensities.

The present limit on exhalation breathing resistance is 5.1 cm H_2O at 120 L/min flow; the limit for inhalation resistance is 10 cm minus this value, or 4.9 cm. If one is willing to accept a 5% decrease in maximal maintainable $\dot{V}O_2$ during a 1-h, maximal-effort escape, from the evidence presented in the figure, there is no reason why it should not be permitted to allow three times the presently permitted exhalation resistance. The 2-mile run, taking substantially less time, suffers a greater decrease in maximum attainable $\dot{V}O_2$ of approximately 13%.

Because human subjects can tolerate high stressors for a short period of time, it is currently a popular belief that short-duration apparatus, such as those for escape, can be permitted to stress the subject more than longer duration apparatus, such as those used for rescue. This philosophy may not apply well to breathing resistance, however. If performance is not to be limited, breathing resistance limits may actually need to be lower for escape than for rescue apparatus. In other words, an escape apparatus, if expected to be used at a high work intensity, should have low breathing resistance so as not to negatively impact performance. A breathing resistance of 8 cm H_2O has been proposed for both inhalation and exhalation resistances for the belt-wearable oxygen self-rescuer being pursued by the Bureau of Mines and MSHA.

SECOND-GENERATION SELF-CONTAINED SELF-RESCUERS

By John G. Kovac[1]

ABSTRACT

It appears to be technologically feasible to develop a second-generation SCSR that is approximately twice the size and weight of an FSR and that has a rated duration of 1 h. This paper summarizes proposed performance criteria, test methods, and approval and certification procedures for second-generation SCSR's. If designed and developed to meet the proposed standards, the resulting SCSR would be safe and reliable, and could be worn by a miner as personal equipment.

INTRODUCTION

Federal mining regulations (30 CFR 75.1714) require that every person who goes into an underground coal mine in the United States must be supplied with a self-contained self-rescuer (SCSR). An SCSR is an emergency breathing apparatus designed for use during mine escape. It must be capable of providing a breathable atmosphere, regardless of the ambient environment, and it must have a rated duration of 1 h. Only SCSR's approved by the Mine Safety and Health Administration (MSHA) and the National Institute for Occupational Safety and Health (NIOSH) can meet the provisions of the regulations.

Four models of MSHA- and NIOSH-approved, 1-h-duration SCSR's are commercially available: CSE AU-9A1, Draeger OXY-SR 60B, MSA 60-min SCSR, and Ocenco EBA 6.5. In order to meet the 1-h-duration requirement, all of the SCSR's are closed-circuit breathing apparatus. Both the Draeger OXY-SR 60B and the MSA 60-min SCSR use potassium superoxide (KO_2), a solid chemical, to generate O_2 and remove CO_2. The CSE AU-9A1 and the Ocenco EBA 6.5 store O_2 as a compressed gas and use lithium hydroxide (LiOH) to absorb CO_2. All of the 1-h-duration SCSR's are much larger and heavier than the conventional filter self-rescuer (FSR), which a miner wears on his belt as personal protective equipment. Unlike SCSR's, FSR's protect only against low levels of CO.

Because of the large size and weight of the current 1-h SCSR's, miners and mine operators have elected to either store or carry and store SCSR's in daily operational use rather than wear SCSR's as personal protective equipment.

It appears to be technologically feasible to develop a second-generation SCSR that is approximately twice the size and weight as an FSR, and that has a rated duration of 1 h, if testing and certification criteria are changed. Such an apparatus has been designated as a person-wearable self-contained self-rescuer (PWSCSR). A PWSCSR meeting these requirements could be worn on a miner's belt and replace the FSR. The mining industry, mine workers, breathing apparatus manufacturers, and MSHA are interested in an emergency breathing apparatus of this kind.

However, much work remains to be accomplished before prototype technology can be expected to function in a reliable manner. Additional research and development must be done to guarantee that the devices will provide safe and appropriate levels of life support capability and will be sufficiently rugged and mineworthy to serve as a replacement for FSR's. Practical deployment options, as well as miner training in the use of PWSCSR's must also be investigated.

The purpose of this paper is to summarize proposed criteria and test procedures for PWSCSR's that would provide safe performance, be rugged for underground use, and be within desirable

[1]Supervisory mechanical engineer, Pittsburgh Research Center, Bureau of Mines, Pittsburgh, PA.

physical limitations. The proposed testing and certification criteria for PWSCSR's are presented in the appendix.

The information presented in this paper is based on the technical recommendations of the Person-Wearable SCSR Task Force, which was an interagency task force composed of representatives from MSHA, the Bureau, and NIOSH. The task force used a variety of sources in formulating its recommendations, including current research findings, conversations with respirator manufacturers and other technical specialists, and discussions with representatives of miners and mine operators.

DEFINITION OF ESCAPE-ONLY DEVICE

There are emergencies in which the need for an escape breathing apparatus is immediate. In these situations, an individual who has an apparatus on his or her person is more likely to survive than an individual who has an apparatus located a distance away. Whether an individual wears an escape breathing apparatus or not depends to a large degree upon the physical requirements of the job and the size of the escape apparatus.

An escape-only device is designed to supply, in an emergency, an atmosphere that will permit the user to escape to a safe environment. The ideal escape-only device is one that is worn by the individual at the job, is rugged so that it will survive its environemnt and perform its function, and is safe for its intended use.

PWSCSR's are escape-only devices intended for use in underground coal mine emergencies.

NEW PERFORMANCE CRITERIA

The proposed performance criteria focus mainly on defining safe, physiologically defensible stressor levels for PWSCSR's. Four physiologically important variables are considered: carbon dioxide (CO_2) concentration, oxygen (O_2) concentration, breathing resistance, and inhaled gas temperature.

CO_2 Level

The present requirement for a 1-h escape apparatus is no more than 1.5% CO_2 in inspired air, during the course of person-testing when sampling breathing gases. Breathing gases are sampled during rest intervals, so gas concentrations are monitored intermittently.

The proposed requirement for CO_2 stressor levels is to raise the 1.5% CO_2 maximum inhaled concentration to 3.0% for a 1-h escape apparatus, while monitoring continuously. The new stressor level is to be determined by time-averaging the inhaled CO_2 levels over the entire duration of the apparatus. When testing presently approved 1-h-duration SCSR's, it was observed that some apparatus exhibited inhaled CO_2 levels exceeding 4% during certain exercise levels and near the end of life. This testing utilized continuous monitoring, unlike that presently conducted at NIOSH. Therefore, in addition to a 3% inhaled CO_2 average level for a 1-h apparatus, a termination peak concentration of 8% CO_2 for a single breath and a 1-min average concentration of 6% CO_2 are added for safety.

Oxygen Level

The oxygen concentration has been increased from 19.5% to 20.9% after the first 3 min. In addition, a 17% minimum O_2 concentration is required for the first 3 min. The reason for these two requirements is to eliminate the need for a self-starter. All presently approved 1-h apparatus exceed 21% O_2.

Breathing Resistance

The present standard measures breathing resistance utilizing a breathing machine as specified in 30 CFR 11.85-3. The maximum resistance for exhalation is 51 mm H_2O or less, and the maximum for inhalation is 100 mm H_2O minus the exhalation resistance.

The new proposal allows for a maximum of 80 mm H_2O for both inhalation and exhalation resistance when measured during the time-duration test. During the high-demand test, the allowable resistance levels are 300 mm H_2O for inhalation and 200 mm H_2O for exhalation.

Inhaled Gas Temperature

The present inhaled gas temperature requirement divides the inspired air into two categories, from 0% to 50% RH (relative humidity), and the other from 50 to 100% RH.

The new criteria allow for alternate wet bulb temperature measurements that automatically take into account temperature and relative humidity. Owing to the complexity of measuring wet bulb temperature, it may be more practical to monitor both relative humidity and dry bulb temperature of inspired air and use conversion charts. Both options are provided for in the criteria.

Time-Duration Test

The Escape Duration Analysis Task Force has determined that 80 L of usable O_2 will allow 95% of the miners to escape from working sections to fresh air. This quantity of O_2 will last 60 min when consumed at a rate of approximately 1.35 L/min. The 50th percentile miner, when performing the 1-h Man Test 4 (30 CFR 11), will use approximately 80 L O_2.

The proposed time-duration test uses a human subject who works at a fixed rate of 1.35 L/min O_2. This is a simple and repeatable test. According to the proposed procedure, a human subject would be placed on a treadmill, and the treadmill speed would be adjusted to require a metabolic demand of 1.35 L/min O_2. After the treadmill speed for a human subject had been determined, the human subject would remount the treadmill with the apparatus to be tested. This approach simplifies the time-duration test and provides repeatability. The apparatus being tested would have to supply the wearer with a breathable atmosphere for 1 h.

High-Demand Test

Man tests contained in 30 CFR 11 provide information on the function of breathing apparatus at various work rates. The new time duration test is performed at a fixed work rate. To determine how well a breathing apparatus functions at various work loads, a high-demand test has been proposed.

During the high-demand test, a human subject walks or runs in place on a treadmill, varying the rate of O_2 consumption, according to a predetermined schedule of exercises. The high-demand test ensures that the apparatus will function across a set of work rates. Stressor levels are monitored continuously to ensure a breathable atmosphere at the different work rates.

The rated duration of the units is established by the time-duration test and need not be achieved in the high-demand test. Time is monitored to ensure that the units can be worn for a minimum time period at the elevated work rates of the high-demand test. The minimum time for a 1-h unit during the high-demand test is 40 min. The time-duration and high-demand tests provide a simple means to objectively determine performance characteristics of the units.

Ruggedness Tests

Ruggedness tests are intended to determine mineworthiness of PWSCSR's that would be worn as personal equipment on a daily basis.

There are four ruggedness tests to simulate a range of environmental conditions likely to be found in underground coal mines. The first test exposes a PWSCSR to high and low temperatures. The second and third tests expose an apparatus to shock and vibration. The fourth test is a submersion test designed to evaluate the integrity of the protective case.

All four tests are applied to an apparatus. Afterwards, the respirator is inspected for safe operation, and then performance-tested.

Human Factors Test

The human factors test addresses ergonomic considerations for comfort and wearability of such apparatus. The human factors test is designed to evaluate the unit while human subjects are performing simple tasks that may be encountered during an escape. As in the time-duration and high-demand tests, physiological varaibles are monitored continuously during the human factors test.

The time required to perform these tests is not related to the rated duration of the units. A 1-h unit is required to be worn and perform the functions listed for 33 min. This time requirement is to assure that the performance of these activities does not reduce the wearing of time of the units.

ADMINISTRATIVE ISSUES

Administrative changes to current approval and certification procedures are recommended.

Third-Party Testing

The most significant administrative change is to allow third-party testing of respirators. A manufacturer can test his own apparatus, or use an independent laboratory. The Government reserves the right to witness all tests at the location specified by the manufacturer. The Government will review the test results, and, if necessary, require retesting.

Special Use Escape-Only Devices

The technical specifications developed by the Task Force apply to PWSCSR's, which are escape-only devices intended for use in underground coal mine emergencies. The proposed approval and certification criteria encourage other industries or organizations to recommend alternate performance criteria, test methods, and procedures for specialized escape-only devices.

Training

Hands-on training is critical for the successful deployment of PWSCSR's. Manufacturers are required to have realistic training units available for purchase.

CONCLUSIONS

The PWSCSR Task Force has developed proposed standards for second-generation SCSR's. These recommendations include new performance criteria, test methods, and procedures for approval and certification. If designed and developed to meet the proposed standards, the resulting PWSCSR would be safe and reliable and could be worn by a miner as personal equipment.

APPENDIX.--PROPOSED TESTING AND CERTIFICATION CRITERIA FOR PWSCSR'S

A. TEST PROCEDURES

MSHA and the Institute reserve their right to witness all tests at the location specified by the equipment manufacturer. The equipment manufacturer will reimburse MSHA and the Institute for travel, subsistence and incidental expenses of its representatives in accordance with Standardized Government Travel Regulations. MSHA and the Institute will be notified at least two months prior to testing in order to determine if instrumentation is adequate to perform tests. The notification will include one unit that represents the escape respirator to be tested. The equipment manufacturer will be responsible for all clearances necessary at the test facility for MSHA and Institute personnel. The equipment manufacturer is responsible for supply test reports, test procedures, instrumentation specifications, calibration traceability, instruction manual and other documentation as requested by MSHA or the Institute. MSHA or the Institute may require instrumentation capability to be verified prior to or during testing, by calibration standards, calibration gases, or by the testing of a respirator whose characteristics are known.

B. UNITS REQUIRED FOR TEST

MSHA and the Institue may require submittal of up to 12 units for testing. The applicant will not be charged for testing.

Units must meet the criteria and the tests outlined in "E" through "H-2". If the units are prototypes, six production units will be tested when available. The production units must meet all approval and certification criteria.

C. CRITERIA

Units must meet all the criteria specified in "C-1 through -4."

C-1. O_2 Levels

Inhaled oxygen will not fall below 17% (dry atmosphere) during the first 3 min of operation. After 3 min, the minimum O_2 level will not be less than 20.9% O_2 (dry atmosphere). During respirator testing, the O_2 will be monitored continuously at the mouthpiece by a sensing unit with at least a 90% response within 100 ms and an accuracy of ±0.1% O_2.

C-2. CO_2 Levels

CO_2 will be monitored continuously at the mouthpiece and the average inhaled CO_2 concentration will not exceed 3% over the time rating of the unit. This value will be an arithmetical average of CO_2 concentration over the inhalation cycle. The arithmetical average of the CO_2 level for any 1-min-time period will not exceed 6.0% for the inhalation cycle; and for a single breath, the average will not exceed 8%.

C-3. Temperature Levels

Inhalation temperatures will not exceed 45° C wet bulb temperature. If wet bulb temperature cannot be measured at the test location by instrumentation having a 90% response within 500 ms with an accuracy of ±1° C, the temperature will meet the requirements in 30 CFR, Section 11.85-18(c).

C-4. Pressure Limitations

The exhalation pressure will not exceed 80 mm H_2O, and the inhalation pressure will not exceed 80 mm H_2O measured at the mouthpiece with a breathing machine as described in 30 CFR 11.85-3. Pressure will be continuously monitored during the time duration and high-demand tests and will not exceed 300 mm H_2O for inhalation and 200 mm H_2O for exhalation when measured by a sensing unit with at least a

90% response within 5 ms and an accuracy of ±1 mm.

D. GENERAL CRITERIA

Devices are intended for escape only and will be made as small and lightweight as possible to improve the user-wearing capability.

D-1. Special-Use Escape Devices

Escape devices for use in specialized areas or industries will be designed for use during escape from those environments expected to be encountered. The following four examples of specialized areas/industries are in no way intended to limit the number of users or types of testing involved. Users with special requirements should meet with the Institute and MSHA to develop performance criteria, test methods and procedures to meet their needs, which will then be distributed to all "interested parties." Limitations will be identified on the manufacturers' labels.

1. Fire Service - Fire service escape devices will have fire-resistant exposed parts, and be self-contained devices.
2. Chemical Industry - Chemical industry escape devices may have exposed parts that must be resistant to chemical vapors expected to be encountered in the specific environment.
3. Mining Industry - Mine escape devices will be self-contained, and must be worn by miners as part of their personal protective equipment.
4. U.S. Naval Shipyards - Confined space escape devices will be self-contained, have fire resistant parts and hood, provide means for carrying by shipyard personnel, and be streamlined, small, and lightweight to allow rapid escape through 20-in accesses.

D-2. Time Duration Test

Escape-only devices will have the time duration of the apparatus as specified by the manufacturer displayed on the labels, and will meet or exceed all criteria listed for the specified duration as evaluated in "F. Time Duration Test."

E. TEST METHOD

The 12 units will be randomly divided into four groups of three units each. These groups will be tested as specified in "F" through "H-2."

E-1. Human Subject Testing Procedure

The equipment manufacturer is responsible for all testing and test equipment, as well as obtaining the human subjects, appropriate medical releases, pretesting physicals, and all other necessary physical and documentary evidence for conducting a safe human subject testing procedure on these apparatus. Appropriate medical attendance at the human subject testing is the responsibility of the equipment manufacturer.

E-2. Human Subject Profile

a. Test subject Type A will be an individual of at least 100 kg body weight.
b. Test subject Type B will be an individual between 65 and 100 kg body weight.
c. Test subject Type C will be an individual with a maximum body weight of 65 kg.

F. TIME DURATION TEST

Three units will be evaluated on human subjects as follows:

a. Human subjects (one of each subject type) will be mounted on a treadmill. The speed of the treadmill, for each human subject, will be adjusted to obtain the following minimum oxygen consumption rates, based on the apparatus time rating, according to the following table:

TABLE A-1. - Apparatus time rating

Time, min	O_2 consumption rate, L/min
10	2.1
15	2.0
30	1.7
45	1.5
60	1.35

For example, if a 60-min device is to be tested, each human subject type would mount the treadmill and the treadmill speed would be adjusted until the oxygen consumption rate is 1.35 L/min. The treadmill speed for each human subject type would then be documented.

b. A human subject, wearing the apparatus to be tested, will mount a treadmill with the speed preset to at least the value determined in "a" above for that subject. Treadmill speed must meet or exceed the value determined in "a" for rated duration of the apparatus.

c. All units will meet or exceed the criteria listed under "C" for the time duration specified.

G. RUGGEDNESS TESTS

Three units with protective cases will be tested as specified in "G-1 through 6," and in the sequence listed.

G-1. Temperature Test

Temperature tests will be conducted by exposure of all three units to a temperature of at least -30° C for 8 h. All three units will thereafter be stabilized at room temperature before exposure to a temperature of 71° C for 4 h. After exposure to a temperature of 71° C, all three units will then be stabilized at room temperature.

G-2. Vibration Test

The three units will be vibrated as per MIL-STD-810B.

G-3. Shock Tests

The three units will be dropped from a height of 1 m onto a concrete floor. Each unit will be dropped a minimum of six times, at least once on each axis.

G-4. Water Submersion Test

The three units will be stabilized at a room temperature of 22° C±2°, and then will be submerged in a water bath until they are completely covered with water, for a period of 1 min. The water bath must be at a temperature of 15° to 18° C. Upon completion of this test, all units must be intact without water penetration to the unit interior.

G-5. Inspection

The three units will be inspected to ensure they are in safe operating condition.

G-6. Time Duration Test for Environmentally Treated Units

All units will meet or exceed the criteria listed under "C" for the time duration specified.

H. OTHER TESTS

H-1. High-Demand Test

One human subject of each profile type (total of 3), wearing an apparatus, will mount a treadmill which will be run at the conditions specified in the High-Demand Test table.

a. Temperature will be monitored during this test and will meet the requirements in "C-3."

b. Oxygen, CO_2, and pressure will be continuously monitored and will meet the criteria in "C-1, C-2, and C-4" respectively.

c. All subjects must complete the demand test.

TABLE A-2. - High-demand test

Activity	Service time, min				
	10	15	30	45	60
Walk................	2	2	2	2	2
Run, uphill........	1	1	1	1	1
Walk................	2	2	2	2	2
Run.................	3	3	3	3	3
Walk................	2	2	2	2	2
Run.................	NAp	2	2	2	2
Walk................	NAp	3	3	3	3
Run, uphill........	NAp	1	1	1	1
Walk................	NAp	NAp	3	11	11
Run.................	NAp	NAp	1	2	3
Walk................	NAp	NAp	2	6	10

Walk - 0% grade, 3.0 mi/h;
Run - 0% grade, 5 mi/h;
Run uphill - 15% grade, 5 mi/h.

H-2. Human-Factors Test

One human subject of each profile type (a total of 3) will perform the tests as specified in the Human Factors Test table after donning a unit.

a. Carbon dioxide and oxygen will be continuously monitored and will meet the requirements in "C-1 and C-2" respectively.

b. Due to the short service times of the 10- and 15-min units, the sequence of activities for human factors testing will be divided into two equal groups. At least one test subject will perform the activities of each group. All three test subjects will perform all the activities listed for the 30-, 45-, and 60-min units.

TABLE 3. - Human factors test

Activity	Service time, min				
	10	15	30	45	60
Bending motion.....	2	3	3	3	3
Stand..............	2	3	1	3	3
Stretching.........	2	3	1	3	3
Stooped walking (127 cm, 2.5 mi/h)	2	3	3	3	3
Crawl (0% grade, 1.5 mi/h).........	2	3	3	3	3
Carry 20 kg (0% grade, 3 mi/h)....	2	3	2	3	3
Twisting...........	2	3	2	3	3
Lie on back side, front.............	2	3	3	3	3
Duck walk..........	2	3	3	3	3
Walk (0% grade, 3 mi/h)...........	0	0	0	3	3
Run (0% grade, 5 mi/h)...........	2	3	0	0	3

I. TRAINING MATERIAL

Manufacturers who obtain an approval are required to have available to users training units that closely duplicate the stressor levels that the approved unit exhibits, and training manuals.

DEVELOPMENT OF A LOW-PROFILE RESCUE BREATHING APPARATUS AND A MINE RESCUE TEAM HELMET

By Nicholas Kyriazi[1]

ABSTRACT

The Bureau of Mines has funded the development of two items of mine rescue team equipment in order to make mine rescue missions safer and more efficient. A 2-h breathing apparatus was developed with the goals of low profile, light weight, positive pressure, cooler breathing air, and low breathing resistance. These goals were achieved through the use of efficient design, proper choice of materials, dual spring-loaded breathing bags, and an internal heat exchanger. The apparatus, the LP-120, has a profile of 10 cm, weights 10 kg, and contains 240 L O_2. A rescue team helmet was also developed that combines the functions of full head protection, breathing apparatus facepiece, communications, and lighting. This helmet was designed to be used with the LP-120.

INTRODUCTION

Since mine rescue teams constitute a small market in the view of equipment manufacturers, their needs remain unfulfilled when they are unique. At present, mine rescue teams utilize equipment that largely has been designed for other purposes and are hampered in their duties by being forced to use safety equipment that only marginally serves their needs. Simply stated, the problem is that the more general the need, the more likely it is to be satisfied; whereas the more unique the need, the more likely it is to be unsatisfied.

The Bureau is attempting to solve the problem of how to advance technology in mine rescue team equipment through subsidizing its development costs. At present, the Bureau is involved with two such developments: a low-profile rescue breathing apparatus and a mine rescue team helmet.

DESCRIPTION OF APPARATUS

The low-profile rescue breathing apparatus is being developed by U.S.D. Corp. through contract H0123008. The mine rescue team helmet is being developed by Gentex Corp. through contract H0252050. Both pieces of equipment are being developed to improve the efficiency, safety, and comfort of mine rescue team members involved in mine rescue and recovery missions.

LOW-PROFILE RESCUE BREATHING APPARATUS

Four agencies are cofunding the low-profile rescue breathing apparatus (LPRBA) contract - the U.S. Bureau of Mines, for use by mine rescue teams on rescue and recovery missions in underground coal mines; the U.S. Air Force, for use by Air Force firefighters in chemical warfare firefighting; the U.S. Federal Emergency Management Agency (subgroup - U.S. Fire Administration), for use by firefighters in situations when long-duration apparatus are needed, such as in high-rise buildings, tunnels, and subways; and the U.S. Coast Guard, for use in cleaning up chemical spills or toxic waste dumps.

The LPRBA is a closed-circuit apparatus and has a rated duration of 120 min, hence its name, the LP-120. Figure 1 shows the LP-120 in its present configuration; figure 2 is a schematic of the apparatus. Since duration is dependent upon O_2 use rate, the apparatus is better

[1]Biomedical engineer, Pittsburgh Research Center, Bureau of Mines, Pittsburgh, PA.

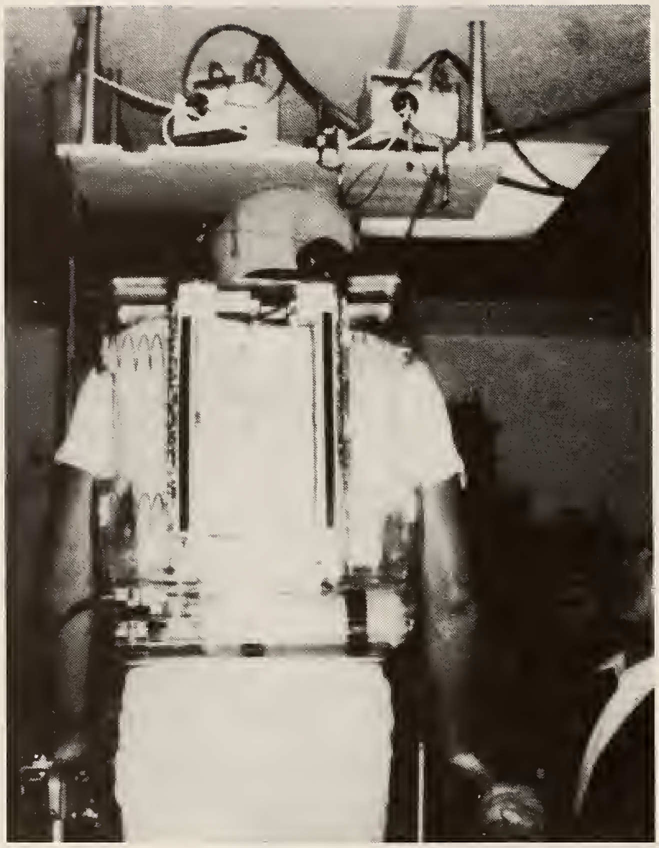


FIGURE 1.—The LP-120.

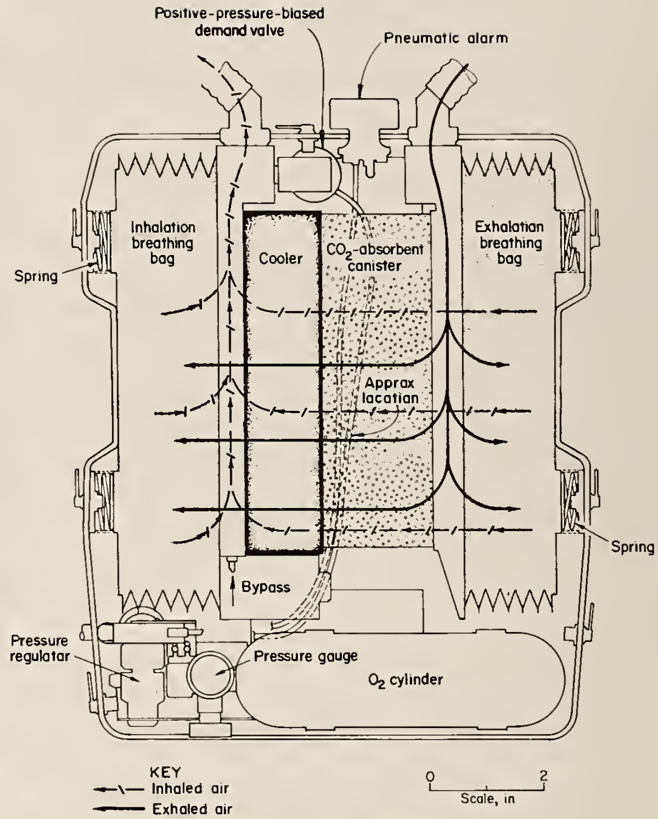


FIGURE 2.—LP-120 schematic.

described as containing 240 L O_2. The apparatus has a number of features that make it unique among closed-circuit RBA's:

1. The most significant feature is the low profile of the apparatus, which is effectively 10 cm from the farthest projection of the back. The actual thickness will be greater than 10 cm, but use of the contour of the human back keeps the 10-cm profile. The most widely used RBA, the Draeger BG-174A, has a thickness of 16 cm and contains 400 L O_2. This is considered a 4-h device but is not usually used for more than 2 h.
2. The weight of the LP-120 is also a significant improvement over that of present apparatus. It is projected to weigh approximately 10 kg compared to 16 kg for the Draeger BG-174A.
3. The apparatus is a positive-pressure system, which means that, in most circumstances, the pressure in the facepiece remains positive compared to ambient. This ensures that any inadvertent leaks will be outward and will not result in any inward leakage that could contaminate the breathing air and endanger the wearer. The positive pressure is maintained through the use of a biased demand valve and two spring-loaded bags.
4. Dual breathing bags enable the breathing resistance to be split between inhalation and exhalation, unlike other closed-circuit RBA's in which most of the effort is placed on exhalation. This is because other apparatus place their single breathing bag in the breathing loop after the CO_2-absorbent canister, or CO_2-scrubber, so that the user must force the air through the chemical bed on exhalation. The use of two breathing bags splits the work of breathing, and, because of the pressure gradient between the bags on either side of the CO_2-scrubber, some of the air flows through the scrubbers by itself.
5. A lithium nitrate, phase-change, heat exchanger is utilized to cool the air after it is heated by the LiOH in the scrubber.

MINE RESCUE TEAM HELMET

The major improvement offered by the mine rescue team helmet (MRTH) (figs. 3-6) is that it consolidates a number of separate pieces of equipment produced by different manufacturers: the hardhat, the facepiece of the breathing apparatus, the cap lamp, and the communications system. All of the separate items have been designed to be compatible with each other, and the MRTH has been designed to be compatible with the LP-120. Following are listed the benefits of the MRTH:

1. The new helmet increases head protection through the use of impact- and penetration-resistant materials and increased coverage at the back and sides of the head.
2. Unlike a hardhat, it will not fall off if you lower your head.
3. It offers a lower profile than hard hats. This will result in hitting the roof less often.
4. The MRTH utilizes a new, smaller light source designed and sold by MSA.
5. The faceplate is removable and attaches to the chest straps of the breathing apparatus when breathing protection is not needed. See figure 6 for a concept drawing.
6. A three-position switch in the communications system enables the wearer to speak to ambient, or the fresh air base, if connected to the lifeline, or to turn off the communications system.

FIGURE 4.—MRTH, side view.

FIGURE 3.—MRTH, front view.

FIGURE 5.—MRTH, back view.

FIGURE 6.—MRTH concept drawing.

TRAINING IN THE USE OF THE SELF-CONTAINED SELF-RESCUER

By Henry P. Cole[1] and Charles Vaught[2]

ABSTRACT

Researchers from the University of Kentucky and the Bureau of Mines have developed a set of training materials designed to increase SCSR donning proficiency. The package presents a generic procedure for the four SCSR's in common use (CSE, Draeger, MSA, and Ocenco). It offers (1) a donning position that is easy and efficient, (2) a donning sequence that moves critical steps (those necessary to isolate one's lungs from the ambient atmosphere) up front, and (3) a set of simplified, easy-to-remember procedural rules that can help miners order the complex array of tasks needed to put a self-contained self-rescuer into use.

This training package has been field-tested with 16 groups of coal industry people in 3 States. The preliminary data suggest that the generic procedure is more efficient than training approaches currently in use. Additionally, the summary statistics indicate a need for consistent and thorough training that includes hands-on performance trials. The optimum interval for such activities has yet to be determined.

INTRODUCTION

The air in the immediate area of an underground coal mine explosion or fire may contain so little O_2 and such high levels of CO that filter self-rescuers would be ineffective. Under such conditions, survivors would have to don the self-contained self-rescuers (SCSR's) rapidly and flawlessly. Miners located at some distance from an explosion or fire might have more time to put their SCSR's into use, but a mine's ventilation system can quickly sweep deadly levels of smoke and CO into relatively distant places. In either case, proficient donning of the device is critical.

Researchers from the University of Kentucky and the Bureau of Mines, in cooperation with MSHA, the Kentucky Department of Mines and Minerals, and several private coal companies, have developed a set of training materials designed to increase donning proficiency. To provide an empirical base for the construction of these materials, the investigators videotaped, under experimental conditions, 50 miners putting on the CSE AU-9A1.[3] This was the model in use at their mine. Each person's performance trial was first timed. The entire donning sequence was then broken into subtasks and evaluated (fig. 1). Finally, errors, interruptions, and omissions that occurred at each step of the procedure were logged. This analysis of the tapes allowed the researchers to target actual or potential problems that might be dealt with by modifying existing approaches to training.

A NEW SCSR DONNING PROCEDURE

Based on the initial findings, an instructor's manual and short videotape demonstration were then prepared for field testing under Bureau contract H0348040. This package presents a generic procedure for the four SCSR's in common use (CSE, Draeger, MSA, and Ocenco). It offers (1) a donning position that is easy and efficient, (2) a donning sequence that moves critical steps (those tasks necessary to isolate one's lungs from the surrounding atmosphere) up front, and (3) a set of simplified,

[1]Educational psychologist, University of Kentucky, Lexington, KY.

[2]Research sociologist, Pittsburgh Research Center, Bureau of Mines, Pittsburgh, PA.

[3]See "Problems in Donning Self-Contained Self-Rescuers," by C. Vaught and H. P. Cole, earlier in these proceedings.

Task	Completed Sequence	Time	First Attempts	Time	Errors
Neck strap on					
Case opened					
Oxygen on					
Goggles saved					
Breathing hose out					
Mouthpiece plug pulled					
Mouthpiece inserted					
Nose clip on					
Head strap on					
Goggles on					
Breathing bag open					
Neck strap adjusted					
Waist strap tied					
Mining cap on					

Time to signaled completion ____________

FIGURE 1.—Example performance scoring sheet for the CSE.

easy-to-remember procedural rules that can help miners order the complex array of tasks needed to don an SCSR.

An Efficient Donning Position

The instructor's manual provides the following directions to the trainee getting ready to put on an SCSR: (1) Kneel and place the unit directly on the mine floor in front of your knees, (2) crouch so that your face is just above the SCSR, (3) lay your cap on the mine floor so that the lamp shines on the unit, and (4) after quickly looping the neck strap over your head, use both hands to don the unit.

This position has a number of advantages. First, in many mines it is not possible to stand erect. The crouching position works well in any seam height. Therefore, all miners can be trained alike. Second, in high coal, crouching keeps the individual's face nearer to the mine floor, where the air and visibility are generally better. Third, with the unit on the mine floor it is easier to work with both hands. Fourth, with one's face directly over the SCSR, it is easier to see the unit. Fifth, the cap and lamp lie still on the same surface as the SCSR. The unit is constantly illuminated and the miner can see what he or she is doing. Sixth, if something is dropped (such as the goggles) the individual has a much better chance of finding it.

A Logical Sequence of Steps

There are three tasks that a miner must complete successfully if he or she is to survive in a rapidly developing toxic atmosphere: (1) activate the oxygen, (2) insert the mouthpiece, and (3) put on the nose clips. When this is done, the individual can take as long as necessary to complete the rest of the donning procedure. For this reason, these "critical" steps were placed ahead of such nonessential tasks as adjusting straps. The crouching position, which allows a person to let the unit rest on the mine floor, makes this possible.

Simply completing the absolute minimum for survival does not mean that a miner has the SCSR secured in a manner that will allow enough maneuverability for him or her to get out of a mine, however. Once an individual's lungs are protected, he or she must then proceed to (4) put on the goggles, (5) adjust the straps, and (6) replace the cap and move out.

An Advance Organizer

Figure 2 shows a practice performance evaluation that includes a simple connect-the-dot method that helps miners to remember the logical ordering discussed above. The scheme is arranged clockwise. The part time, which is recorded immediately upon completion of the critical steps, helps to break the procedure into two groups of activity: (1) isolate the lungs and (2) prepare to escape.

Research has shown that when presented with a lengthy ordering of tasks to be done, what people forget is not how to perform individual steps but the overall sequence. Each of the six points in this advance organizer helps to cue the person's recall of the appropriate discrete tasks it includes. The "3 + 3" organization is much more mnemonic than the list of a dozen or so steps typical of existing training materials. For example, it is much easier for a miner to remember to "activate oxygen" and to do this first than it is for him or her to recall and do in proper order all the separate parts of that task.

A Caveat

Of course, the "chunked" sequence given above assumes that the trainee has been filled in on the details of how to activate the oxygen and to do all the other tasks for the particular model of SCSR he or she is being trained on. Likewise, it is assumed that the trainer has gone over details of how to care for and inspect the units and has discussed the storage plan for his or her mine. The generalized sequence outlined here deals solely with how to get a unit on efficiently; it does not replace other parts of a total SCSR training session. When used for its intended purpose, however, the procedure has potential to reduce significantly

Performance Evaluation for ______________________ Date__________

1. Did the miner answer the following?

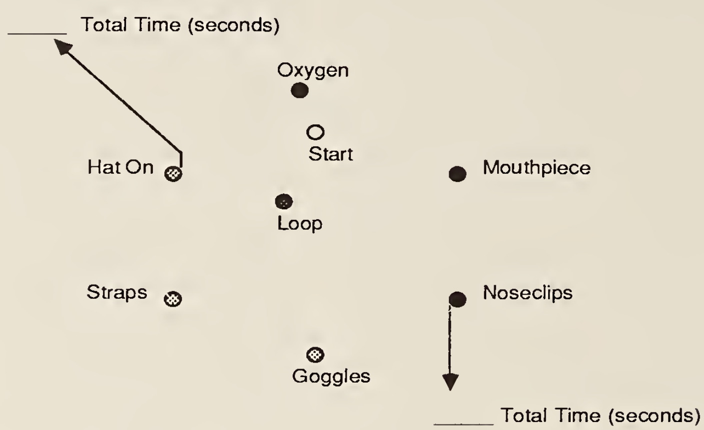
   A. Name the exact place where you started working last shift.

      ________ Yes ________ No

   B. Tell me how to get to the nearest SCSRs from that place.

      ________ Yes ________ No

2. Connect the dots in the diagram below to show the steps the miner took in donning the SCSR. DO NOT TOUCH THE DOT IF HE OR SHE DID THE STEP INCORRECTLY.



3. After the task is completed please list any errors that need to be corrected and then correct them.

Trainer's Signature______________________

FIGURE 2.—Example SCSR evaluation form.

the errors miners make when donning the devices.

FIELD TESTING THE PROCEDURE

The training package has been field-tested with 16 groups of coal industry people in workshops held in 3 States. The workshops were attended primarily by trainers and by State and Federal inspectors. The purpose of the field tests was to add to the knowledge of how long it takes individuals to put on an SCSR, to document the types of errors they make, and to improve the materials aimed at teaching and assessing a simpler and more time efficient way to put the unit into use.

Conduct of the Workshops

All workshops followed the same format. An instructor who had helped design the procedure first talked about the training activity and discussed the factors that had led to its development. He then explained that the people present would be introduced to five innovations: (1) a donning sequence that rapidly gets the miner on oxygen, (2) fewer steps to remember to don the SCSR fast and correctly, (3) a donning position that makes the

new sequence possible, (4) a performance evaluation that records skill, errors, and completion times for critical and secondary tasks while helping observers learn the procedure, and (5) the use of a simple, adjustable mine simulator. With the aid of overhead visuals, the instructor next outlined in detail what the participants would be doing.

After this introduction, the entire group was shown short videotapes of two trainers putting on each of the four SCSR models while in the simulator. The instructor pointed out the critical donning steps, reviewed the advantages of the demonstrated position and sequence, noted the times these two trainers required to complete the critical steps, and opened the floor for discussion. Following a brief question and answer period, the participants were sent to their choice of small workshop sessions devoted to the CSE, Draeger, MSA, or Ocenco.

In each small group a trainer presented tips on the care, inspection, and placement of the SCSR in question. He then gave instruction on the proper way to do the various subtasks, such as opening the case. After this preliminary, the trainees reviewed the videotape dealing with their particular model. One at a time, individuals next put on a miner's belt, filter self-rescuer, cap, and cap lamp and entered the simulator, which was adjusted to approximately 40 in. At a signal from the trainer, the person in the simulator began to don the unit. During each donning trial, which was done with no prompting from anyone, other members of the group worked in pairs to evaluate the performance. While one person in each pair observed the trainee's sequence and recorded it on the form shown in figure 2, the other noted the part time (for critical tasks) and the total time. At the end of each trial the trainer, who had also been evaluating the performance, noted and corrected any error that had been made.

Findings From the Workshops

Table 1 presents summary statistics for individuals donning the four SCSR's in workshops in eastern and western Kentucky. No data are reported for West

TABLE 1. - Summary of data collected from SCSR donning workshops

SCSR type and site	Test date	Critical time, s			Secondary time, s			Prior donning[1]		Perfect donning sequence, % of total
		N	Mean	SD	N	Mean	SD	Mode[2]	No.[3]	
Draeger:										
E Kentucky....	1/22	7	17.00	5.77	7	55.00	20.78	NAp	NAp	28.57
	1/28	27	23.89	10.61	27	64.70	29.08	3	12	62.96
	1/29	15	20.47	4.93	15	52.20	19.18	0	11	53.33
W. Kentucky....	3/18	16	16.25	4.97	17	41.12	17.09	0	6	22.22
	3/19	17	17.53	6.71	18	59.17	19.45	0	11	38.89
Ocenco:										
E. Kentucky....	1/22	11	26.27	5.87	11	79.45	26.16	NAp	NAp	63.64
	1/29	11	33.73	10.00	11	82.45	24.11	0	9	45.45
W. Kentucky....	3/18	16	26.44	5.66	15	69.06	25.42	0,1	3,3	[4]11.76
	3/19	17	38.64	11.10	19	84.32	19.08	0	16	47.37
CSE: E. Kentucky	1/22	9	21.67	4.77	9	68.88	17.95	NAp	NAp	66.67
	1/29	16	24.94	11.39	16	62.44	20.91	0	9	64.71
MSA: E. Kentucky	1/29	10	17.90	5.15	10	51.50	14.35	0	8	50.00

NAp Not applicable. [1]Experience with this model.

[2]Mode = most frequently occurring value in a set where different values may occur more than once.

[3]No. = number of people who gave the modal response for their group.

[4]Of the 17 trainees, 9 adjusted the straps before donning their goggles. Although this deviates from the perfect sequence, it is not a critical error.

Virginia owing to the small number of persons in trainig sessions for each unit. The table presents (1) the means and standard deviations for critical tasks and secondary tasks, (2) the modal response and frequency for the number of times trainees had donned the model before, and (3) the percent of individuals who recorded a perfect sequence on the first trial. Since all participants at a workshop were encouraged to try every SCSR being used, there is a confounding factor: no attempt was made to control for whether an individual had just gotten hands-on training with the Ocenco before donning the CSE, etc. There might be some negative or positive transfer of training in such situations, but that was ignored for purposes of the present research.

Table 1 reveals some interesting findings. First, it will be noted that the critical tasks necessary to isolate one's lungs from the ambient atmosphere take up significantly less than half the total time needed to get most units on. When it is considered that some existing training materials recommend doing one or more of the critical tasks near the end of the donning sequence, it can be seen that the procedures suggested in this paper are an improvement from the standpoint of efficiency. Second, even the simplified sequence offered in the workshops is difficult to get correct on the first trial. The highest percentage (66.67%) of people having a perfect donning performance was recorded for the trainees putting on the CSE at the workshop in eastern Kentucky. Although many of the errors recorded could be considered minor, the figures nevertheless underscore the need for hands-on training. That brings up the third point: the modal prior donning experience for most persons in most workshops was zero. Unless most participants skipped the workshops devoted to the models in use at their operation, which is unlikely, the implication is that there are a number of trainers teaching miners how to don the SCSR who have never themselves had one on.

CONCLUSION

The preliminary data tabulated here suggest there are ways to make a more efficient donning sequence for each model of SCSR. Additionally, the summary statistics indicate a need for consistent and thorough hands-on training as well as further study to determine the optimum interval for such activities.

DEVELOPMENT OF AN AUTOMATED BREATHING AND METABOLIC SIMULATOR (ABSTRACT)[1]

By Nicholas Kyriazi[2]

The U.S. Bureau of Mines has been developing breathing and metabolic simulator technology since 1970. Breathing simulation has been widely achieved throughout the world and used in the testing of open-circuit breathing apparatus, but satisfactory metabolism simulation has not been achieved. This situation required that the testing of closed-circuit breathing apparatus, which are the only type used in mines, be done using human test subjects. The goal was a machine that could accurately simulate both the breathing and the metabolic functions of a human being for testing of closed-circuit breathing apparatus. The advantages of using such a machine instead of a human being for testing respiratory protective devices lie in its ability to quantify metabolic input, its repeatability, and the lack of a need to deal with the vagaries of human subjects.

The foregoing paragraph abstracts the contents of a report describing the breathing and metabolic simulators that have been developed and used by the Bureau over the past 15 years; this report is available as Bureau of Mines Information Circular (IC) 9110. A free single copy of this report may be obtained by writing:

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[1]Reprinted from Bureau of Mines Information Circular 9110.

[2]Biomedical engineer, Pittsburgh Research Center, Bureau of Mines, Pittsburgh, PA.

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